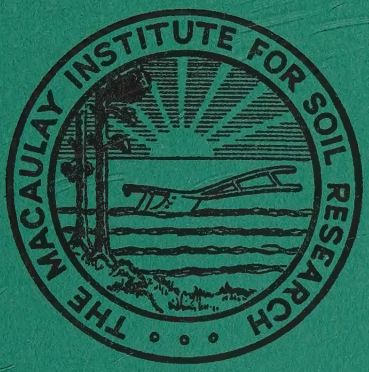
# THE MACAULAY INSTITUTE FOR SOIL RESEARCH

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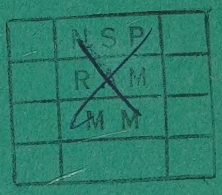
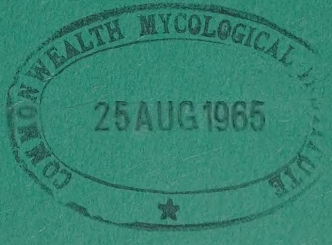
# ANNUAL REPORT 1961-1962



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The Macaulay Institute for Soil Research.

Members of the Macaulay family at Dr T. B. Macaulay's portrait.
*Left to right:* Mrs D. L. Macaulay, Mrs H. W. K. Hale, Mr D. L. Macaulay, Mrs and Mr P. D. Woods.

# THE MACAULAY INSTITUTE FOR SOIL RESEARCH

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(Founded 1930)

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Beate Berner (Statens Rästofflaboratorium, Østmarka, Trondheim, Norway).
D. J. David (C.S.I.R.O. Division of Plant Industry, Canberra, Australia).
A. R. K. Gaafar (College of Agriculture, Cairo, Egypt).
M. M. Guha (Rubber Research Institute of Malaya, Kuala Lumpur, Malaya).
Liselotte Heller (Geological Survey, Jerusalem, Israel).
I. D. Hill (Department of Soil Science, University of Oxford).
F. S. C. P. Kalpage (Department of Agriculture, University of Ceylon, Peradeniya, Ceylon).
J. H. Kirkman (Ministry of Agriculture, Fisheries and Food Scholar).
W. Myśków (Instytut Uprawy, Nawozenia i Gleboznawstwa, Pulawy, Poland).
N. E. Nissim (National and University Institute of Agriculture, Rehovot, Israel).
K. Oland (Ullensvang Research Station, Hardanger, Norway).
S. Oliver Moscardo (Instituto de Edafologia y Fisiologia Vegetal, Madrid, Spain).
Marija F. Siroki (Institut za Metalurgiju, Sisak, Yugoslavia).
P. A. Tallantire (Cheadle Hulme, Cheshire).
I. H. Tunckale (Orman Fakültesi, Istanbul Üniversitesi, Büyükdere, Istanbul, Turkey).

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# INTRODUCTION

On 21st September 1962 the new building, which had been under construction since August 1958, was formally opened by Mr Douglas L. Macaulay of Montreal, a son of the Founder of the Institute. Mr Macaulay was accompanied by his wife, his sisters, Mrs Hale and Mrs Woods, and his brother-in-law, Mr Woods, all of whom had come to Aberdeen specially for this important landmark in the development of the Institute. The Opening Ceremony marked the virtual completion of the constructional work and the new premises have now been fully occupied.

The new building is located on the northern boundary of the Institute lands with its main frontage facing south and the north front adjoining a projected trunk road to the west. The main block, two floors high with a frontage of 228 feet and a depth of 161 feet 6 inches, is disposed around a central court, in which the separate library block has been sited, with access from the entrance hall. The slope of the ground made it possible to have a lower floor at the east side of the main block together with a separate wing at this level, giving workshop and laboratory servicing accommodation with convenient access for goods delivery and with elevator facilities to the upper floors. The length of the north frontage is 301 feet and the total floor area within the outer walls is some 60,000 square feet.

The building is in modern style and was designed for high fire resistance, having a reinforced concrete frame with panel infilling of brick and foamslag cavity walls. It is finished to the requirements of the specialized types of work carried out in the various departments. In particular, precautions have been taken to avoid the problems of chemical corrosion by eliminating as far as possible exposed metal fittings in laboratories. Benches and other furnishings and the frames of the double glazed windows are of hardwood. Individual roof mounted fans have been provided for fume extraction, and precautions have been taken to reduce noise and vibration from fans, compressors and other machinery. In certain sections of the building which house spectrochemical and other specialized equipment, provision has been made either for full air-conditioning or for temperature control and air filtration. Paints capable of resisting fume attack and free from biologically important metals have been employed, and as far as possible uncovered plaster and lime surfaces have been avoided.

Electrical power is obtained from the North of Scotland Hydro-Electric Board 11,000V supply, the high tension switchgear, transformers, and distribution system being part of the Institute installation. Present capacity provides for sustained loads of 1,250 kw and allowance has been made for possible long-term development. Electrical underfloor heating has been installed throughout the building, with facilities for replacement of defective heating elements from corridor ducts. The connected load of the heating

system is 533 kw, metered at off-peak tariff rate. Hot water requirements are met through a ring main system by three 400 gallon 42 kw electrically heated cylinders. Laboratory lighting is by means of fluorescent fittings which are plastic covered to prevent corrosion. Single and three phase supply sockets are adequate to meet reasonable future requirements, and facilities for distribution of non-standard electrical supplies have been provided where necessary.

Removal to the new laboratories caused less disruption in normal activities than was anticipated and progress in the research programme has been well maintained.

Valuable contacts with research and educational organizations, both at home and abroad, have been extended by Institute representation at meetings bearing on its scientific activities, by the provision of facilities for visiting workers from many overseas countries, and by a steadily increasing exchange of scientific publications. During the winter months two members of the staff of the department of Soil Survey were seconded to assist in the soil survey of West Pakistan and, in the course of the year, members of staff attended meetings in the U.S.A. on spectroscopic work, in Belgium on plant analysis and fertilizer problems, on biochemistry, and on soil classification, in Finland on the survey and utilization of peat resources, and in Italy on plant physiology. In addition to receiving a very large number of short-term visitors from twenty-two countries, facilities for longer-term work have been made available to visiting scientists from Australia, Ceylon, Egypt, Israel, Norway, Poland, Spain, Turkey, and Yugoslavia. Various members of staff have again served on technical and advisory committees appointed by the Secretary of State for Scotland and by such bodies as the Department of Agriculture and Fisheries for Scotland, the Ministry of Agriculture, Fisheries and Food, the Agricultural Research Council, and the Forestry Commission, as well as on other scientific panels and groups.

As in previous years, the broad aim of the research in progress has been to obtain from field, pot, greenhouse, and laboratory studies of soils and plants information of value in the maintenance and improvement of soil fertility from the standpoint of both crop production and animal requirement.

It is with deep regret that the death on 19th July 1962 of Sir Thomas Murray Taylor, Principal and Vice-Chancellor of the University of Aberdeen, is recorded. Sir Thomas served as a co-opted member of Council for nearly fourteen years, and the Institute shares with many other organizations the grievous loss of one who contributed so much to the public life of a wide community.

*30th September 1962.*

## PEDOLOGY

All sections have now moved into the new building and this for the first time enables the department to function as a unit with various communal services. The accommodation recently occupied by the sections of Peat Ecology and Forest Soils includes rooms for plant drying and storage, mapping, pollen analysis, and botanical studies. Normal laboratory facilities are shared by the two sections, enabling co-ordination of systematic analytical work. The major pieces of equipment which have been added are a pressure membrane apparatus for studying soil moisture problems, phase contrast equipment for microscopic work, and a rock section cutter. The electron microscope laboratories are now available for the purpose for which they were designed and part of the equipment has been received; the electron micoscope itself is expected early in 1963.

During the past year the value of the improved conditions in the new building has become clearly apparent in the work of the sections transferred. Not only can a greater volume of work be performed, but the facilities available, in many instances, enable greater precision in results to be obtained. With the installation of the remaining two sections, such improvements should become clear in the work of the department as a whole.

Close collaboration has continued with the Forestry Commission and the Scottish Peat Committee, as well as with other departments of the Institute. Samples have been examined on behalf of organizations in various overseas territories, the Department of Agriculture and Fisheries for Scotland (Peat Section), the Arthur D. Little Research Institute, and the Universities of Aberdeen and Durham.

Dr F. S. C. P. Kalpage of Ceylon, Dr S. Oliver Moscardo of Spain, and Mr P. A. Tallantire, Cheadle Hulme, Cheshire, have spent extended periods in the department, and other visiting workers from Egypt, Germany, Israel, and Norway have paid shorter visits to study the methods in use. Mr J. H. Kirkman, a Ministry of Agriculture, Fisheries and Food Research Scholar, has commenced a study on the nature and distribution of amorphous inorganic materials in some Scottish soils.

Members of staff have attended, *inter alia*, meetings of the Scottish Peat Committee (Moss Survey Group), the British Society of Soil Science, the British Association, the International Executive Committee of the Second International Peat Congress at Leningrad, the Forestry Commission Research Branch Programme Conference, and the Clay Minerals Group of the Mineralogical Society. Dr R. C. Mackenzie attended a meeting on the morphology of fine particles at Hanover and the Eleventh National Clay Conference at Ottawa, at which he delivered, by invitation, the key-note address[24]. Dr Mackenzie also acted as visiting lecturer at seminars on clay mineralogy held at the Virginia Polytechnic Institute, Blacksburg, Va., and

at Pennsylvania State University, University Park, Pa.; in addition he visited several institutions carrying out work on soils, clays, and associated materials in the eastern U.S.A. and Canada, and attended the annual meeting of the Soil Science Society of America at Cornell University. Mr R. A. Robertson visited various centres in Finland to study current peat research there.

*Soil Mineralogy*

The study of the mineralogy of the soil is being prosecuted in two sections—in the section of Soil Mineralogy by X-ray and optical techniques and in the section of Physical Chemistry by thermal, chemical, and physical methods. All methods contribute information of value and it is only by considering this work as a whole that valid deductions can be drawn regarding the nature and characteristics of the minerals in soils and regarding pedogenesis. Over the last few years, too, the value of infrared spectroscopy has been apparent and close collaboration is continuing with the department of Spectrochemistry.

*Separation and Pretreatment of Samples.* For mineralogical examination it is customary to separate soils into their particle size fractions by sedimentation techniques, and the fine sand and clay fractions receive particular attention. One of the most common reagents employed in the pretreatment of soils and clays is hydrogen peroxide which is used to destroy organic matter. It has been known for some time that under certain conditions calcium oxalate is formed by such a treatment, but recent investigations in this department have shown that much more serious effects may be introduced. Thus the presence of soluble and insoluble oxalato-aluminates and oxalato-ferriates has been demonstrated in peroxidized clays by differential thermal and infrared absorption techniques. Since, therefore, hydrogen peroxide treatment may lead to significant changes in properties, alternative procedures for removing organic matter are currently being checked.

*Fine Sand and Silt Fractions.* The systematic examination of fine sand fractions from Scottish soil profiles has continued and samples from south-west and north-east Scotland have been studied by optical methods. Sand and silt fractions from four soils from Ceylon, which were studied in detail by X-ray and optical techniques, showed that the more resistant and stable species of the fine-sand minerals (quartz, zircon, iron oxides, etc.) were concentrated to a greater degree in the most weathered soils, whereas micas and ferromagnesian minerals persisted in the young and less weathered profiles. Silt and sand fractions from some Turkish soils were also examined.

*Clay Fraction.* Soil clays consist of a mixture of crystalline and amorphous components, but since the latter may exist in all particle size fractions only the crystalline components will be considered under this heading.

The systematic examination of soil clays by X-ray and differential thermal methods has continued and samples from south-west and north-east Scotland have been studied. The usual suite of minerals has been observed. Several soil clays from north and north-east Scotland have also been checked to see whether variations could be correlated with specific pedological factors. A

paper discussing the influence of soil-forming factors on clay mineral genesis[1] has now appeared.

A number of soil clays from other localities have also been examined. In soils from Tanganyika kandite was the predominate clay mineral and was associated with varying amounts of gibbsite and goethite. Detailed examination of the four soils from Ceylon showed that the mineralogy could be correlated with parent rock, soil type, and maturity of the profile. Thus, a young, reddish-brown earth contained smectite along with illite and kandite in the clay fraction, whereas a corresponding mature profile contained only illite and kandite; the clay from a red-yellow latosol was nearly pure kandite, but a yellow podzolic soil on the same parent material contained over 10 per cent. gibbsite along with kaolinite.

Many pure minerals likely to occur or related to those occurring in soil clays were examined by thermal, physical, and chemical methods during the year. In continuation of the work on phosphate minerals two joint papers have been submitted for publication: one of these concerns X-ray, differential thermal, and infrared studies on aluminium and ferric phosphates[25] and the other organic soil phosphates[26]. Dehydroxylation and rehydroxylation studies on montmorillonite and pyrophyllite, which it was hoped might lead to a better understanding of the type of montmorillonite occurring in soil clays, have continued. The value of thermogravimetry as an adjunct to differential thermal analysis was especially noted in the determination of optimum temperature for rehydroxylation, which involved accurate measurement of the amount of structural water in the rehydroxylate[27]. A paper on the ageing of alumina gels[2] has now appeared, as has a review of differential thermal analysis with particular reference to its use in analytical chemistry[3].

A small proportion of the large number of X-ray diffraction patterns recorded in recent years has shown a line at about 8Å which could not be ascribed with certainty to any specific mineral. Re-examination of these in more detail showed that this line was sometimes associated with an amphibole, but that in certain soils derived from Old Red Sandstone till it may arise from an interstratified mineral—probably a regularly interstratified illite-chlorite.

*Amorphous Inorganic Material.* Detailed examination of clays from the surface and basal horizons of a number of Scottish soil profiles, in collaboration with the department of Spectrochemistry, has shown that these clays contain a proportion of highly hydrated amorphous material resembling allophane in its properties and that this material is especially high in clays from surface horizons with high organic matter content[28]. Selective dissolution techniques for the determination of such amorphous inorganic material have been extensively investigated. Samples of commonly occurring crystalline soil-clay minerals, allophane, and silica gel have been subjected both to successive extractions with cold 5 per cent. sodium carbonate solution and to successive digestions on a steam bath with the same solution. Cold extractions followed by hot have also been tested. Since finely particulate crystalline minerals may dissolve as easily as amorphous inorganic material, the

results must be interpreted with a certain amount of caution. X-ray examination has been utilized in an attempt to evaluate any changes induced by these treatments.

Because of the fineness of amorphous inorganic material in soil clays, it seems likely that they may have a very high surface area. Consequently, an apparatus has been constructed for determining this by means of the Brunauer-Emmett-Teller nitrogen adsorption technique. This apparatus has now been calibrated and specific surface area measurements carried out on a series of crystalline clay minerals. Other methods for determining surface area, such as adsorption of *o*-phenanthroline from aqueous solution and ethylene glycol retention, are also being checked. Results so far obtained are encouraging.

*Rock Weathering.* Weathered rock samples examined by X-ray and optical methods included an ultrabasic rock from Scotscalder, Caithness, which is composed of large crystals of the mica phlogopite, a colourless amphibole, and serpentine. During pedological weathering a chlorite is formed from the mica and the overlying soil is rich in large golden flakes of this mineral.

*Clay-Organic Complexes.* As part of the study of the complexing of clay with organic matter, differential thermal curves of complexes formed by commonly occurring crystalline and amorphous clay minerals with piperidine have been determined in oxidizing and inert atmospheres. Thermogravimetric curves have also been obtained. The results indicate that piperidine saturation is of value in the diagnosis by thermal means of montmorillonite and allophane and may have a bearing on the mechanism of formation of natural complexes in soils.

*Soil Analysis*

Analytical determinations have been completed on the soils collected by the department of Soil Survey during the 1960 field season and on about one-third of the samples collected during the 1961 field season. On the remainder of the 1961 samples pH determinations have been completed and several other determinations are well in hand. The total silica, iron, and aluminium contents of clay fractions separated from 60 soils have been determined. Miscellaneous analyses of 60 samples have been carried out for other departments of the Institute. A paper describing a punched-card system for recording soil profile information[30] has been accepted for publication.

Collaborative work with the department of Soil Survey on the ability of aqueous extracts of pine needles to complex with sesquioxides has continued.

*Peat*

The sections of Peat Ecology and Forest Soils are both involved in investigations on peat. The former is interested in broader aspects, including the detailed study of peat deposits and problems related to the utilization of peat and associated soil types, whereas the latter is concerned with such aspects of peat as affect afforestation.

A survey of the major peat deposits on Sheets 87/89 (Peterhead/Fraserburgh), 77 (Aberdeen) and 76 (Inverurie) has been completed. An account of the main features of these bogs together with profile diagrams and certain chemical, physical, and pollen analytical data will appear in the appropriate Soil Survey Memoir. The introductory work on the assessment of nutrient content of peat with a view to afforestation has also been completed and a report published[4]. Future work will be undertaken in collaboration with the Research Branch of the Forestry Commission, who will be responsible for the survey of areas for afforestation. Samples from the Trial Forest at Rumster, Caithness, are being examined.

Analysis of peat samples for the Department of Agriculture and Fisheries for Scotland (Peat Section) has continued. During the current year over 1,000 samples have been received from peat deposits in Sutherland, Caithness, and Aberdeenshire. Physical and chemical determinations have also been carried out on peat and herbage samples from various field experiment centres and on material submitted by other departments of the Institute.

Further samples for yield, chemical composition, and botanical analysis have been taken from the 145 grass/clover plots at Gardrum Moss, Stirlingshire. This experiment, which was set up in collaboration with the department of Soil Fertility in 1957 to investigate the effects of different rates, forms, and combinations of lime and fertilizers on the establishment and development of grassland on deep peat, is now being concluded.

Close collaboration has been maintained with the Scottish Peat Committee both in relation to the publication this year of its second Report and to the proposed publication of moss survey data on a regional basis.

*Mineralization of Nitrogen.* The results from the ploughing experiment at Glentrool, Kirkcudbrightshire, analysed by the section of Statistics, show that only in July 1961 was there more mineral nitrogen under the deep ridges than under the shallow ridges. The duration of this experiment is being increased to four years with peat sampling at wider intervals, in order to allow time for any differences to appear as the peat dries.

*Ecology.* The first phase of the joint experiment on the balance of water and of plant nutrients in different peat ecosystems at Blacklaw Moss, Lanarkshire, has been completed. Work is now in progress to analyse the three years' results (January 1959-December 1961) in order to study the water balance of the 17-acre peat catchment in its comparatively undisturbed state. The area has since been drained and within it seven sub-catchments are being established. The second phase will investigate the effect of drainage on the run-off pattern from the main catchment and, simultaneously, the sub-catchments will be calibrated prior to the introduction of different forms of utilization and management.

At Coalburn Moss, Lanarkshire, a study of the significance of soil moisture in the development of vegetation and soil characteristics on deep peat has continued along the lines previously reported. Work on the unimproved plots is nearing completion, but the improved series will probably be maintained in order that certain vegetation trends can be further assessed.

A field experiment has been laid down at Moss Maud, Aberdeenshire. There the grass/clover plots previously described have been retained for the purpose of carrying out further root investigations. The range and variation in temperature and moisture conditions in deep peat are also being investigated at two sites on the bog. Ground water levels, soil moisture contents, and potential evapotranspiration are measured weekly and rainfall is recorded continuously. Instruments, at present being calibrated in the laboratory, will be installed to record soil temperatures at various depths. Root studies using an improved radioactive tracer technique, an account of which has been published as a joint paper[5], have continued at two centres.

Investigations on heather burning are now being co-ordinated by a group comprising members of the Hill Farming Research Organization, the Nature Conservancy, and the Macaulay Institute. Particular attention is being given to the amount of nutrients found in different stands of *Calluneta* and the nutrient input to the ecosystem from rain water.

*Pollen Analysis and Quaternary Research.* In collaboration with the department of Soil Survey, quaternary studies have continued at a number of locations in Easter Ross. Pollen diagrams from sites near Alness and Tain have been completed and have helped in a better understanding of pedological problems and early post-glacial environments. Further stratigraphical and pollen investigations on high altitude peat have been carried out on samples taken from Hill of Fare, Aberdeenshire, and Coire Bog, Ross and Cromarty. In particular, significant evidence on the past distribution of pinewoods is accruing from this work.

Pollen analysis of material from archaeological excavations in the upper Tweed Valley and from the islands of Arran and Tiree is being undertaken with a view to giving help in dating important sites.

*Requirements of Trees*

*Nutrients.* It has been known for some time that there are large areas of forest which would respond to nitrogen fertilization, but it has seemed rather unlikely that such responses would cover the cost of fertilizing, because of the short duration of the response. To provide information on this aspect, experiments have been laid down in forests at Broxa, Yorkshire, Inshriach, Inverness-shire, and Culbin, Morayshire, to compare different rates and frequencies of application of nitrogen.

Regular analyses of foliage from the sulphur fertilization experiment at Culbin have shown that the inorganic sulphur fraction in the foliage has been greatly reduced in the plots with added nitrogen. The visual symptoms of sulphur deficiency mentioned in last year's Annual Report did not appear this season. The crops from a greenhouse experiment, designed to evaluate foliage analysis as a method for assessing the sulphur status of conifers, have been harvested and await analysis.

The number of foliage analyses carried out for the Forestry Commission has increased. Samples from experiments and from areas of poor growth have been analysed for major nutrients. Fertilizer recommendations for Forestry Commission and private nurseries, based on soil analyses by the

department of Soil Fertility, have continued at the usual rate. A paper on upland soils and their potential for tree growth was read at the British Association meeting in Manchester.

*Soil Aeration.* Early work by the Forestry Commission has shown that ploughing and drainage are essential for the establishment of trees on peat and on many heath soils. The increased aeration which results from such preparation is one of the most important factors permitting healthy growth. Vigour is improved by the increased supply of oxygen to the roots and by the greater availability of nitrogen, the mineralization of which follows aeration. Methods for studying soil aeration have been examined, and a study of the oxygen requirement of trees has commenced.

## SOIL SURVEY

During the 1962 survey season approximately 525 square miles have been mapped on a scale of 2·5 inches to 1 mile in the following areas: 40 on Sheet 85 (Rothes); 55 on Sheet 84 (Nairn); 55 on Sheets 48 (Perth) and 49 (Arbroath); 90 on Sheet 39 (Stirling); 125 on Sheets 32 (Edinburgh) and 24 (Peebles); 160 on Sheets 7 (Girvan) and 8 (Carrick). The mapping of Sheet 39 has now been completed, and it is anticipated that work on Sheets 48 and 49 and on Sheets 7 and 8 will be completed in 1963. A number of soil monoliths have been collected and 206 soil profiles have been sampled and described.

Soil survey maps for Sheet 77 (Aberdeen) and composite Sheet 87/97 (Peterhead/Fraserburgh) have been published. In preparation are the maps for Sheet 14 (Ayr), composite Sheets 33/34 and part of 41 (Haddington/Eyemouth/North Berwick) and 66/67 (Banchory/Stonehaven).

A memoir entitled *The soils of the country round Aberdeen, Inverurie and Fraserburgh*[32] is in the hands of the printer, and memoirs to cover the Sheets for Ayr, Haddington/Eyemouth/North Berwick, Banchory/Stonehaven and Forfar (Sheet 57) are in preparation.

Further records of the vegetation of Sheet 39 (Stirling) have been made, using plant sociological methods, and the vegetation of the Perth and Arbroath Sheets is being recorded in a similar manner. The statistical analysis of the vegetation and site data from Torn na Gabhar, Aberdeenshire, is being undertaken, and a punched-card system has been designed to aid the analysis. A brief account of the vegetational changes in the permanent quadrats at Scare Hill Forest Reserve, Tillyfoure, Aberdeenshire, has been prepared for the Forestry Commission in collaboration with the section of Peat Ecology.

A paper on the general principles of classification with reference to soils[6] has been published, and one on a punched-card system for soil profiles[30] is in press. A paper on the principal genetic soil groups of Scotland[33] is being submitted to the Joint Meeting of Commissions IV and V of the International Society of Soil Science to be held in New Zealand, and a description of the soils of north-east Scotland[34] has been prepared for the forthcoming Aberdeen meeting of the British Association for the Advancement of Science. Papers are in press on the indurated horizon of podzolic soils in north-east Scotland[35], on copper-deficient soils in south-east Scotland[36], and on a method for determining the relative ages of readvance moraines[37].

*Ad hoc* activities have included: (a) Collection of agricultural and economic data on 72 fields on 24 different farms in East Lothian and Berwickshire, in conjunction with the Edinburgh and East of Scotland College of Agriculture. This investigation has yielded information on the profitability of the three dominant soil types in south-east Scotland. A similar investigation has been carried out on 78 fields in the Stirling area, in col-

laboration with the West of Scotland Agricultural College advisory officers. (b) A field excursion in south-east Scotland for agricultural advisory officers of the Edinburgh and East of Scotland College of Agriculture, to demonstrate the main soil series and discuss their properties. (c) Discussions in the field and information exchanged with officers of the Geological Survey on the soils and drifts of Sheets 33 (Haddington), 39 (Stirling), and 95 (Elgin). (d) Co-operation with the Forestry Commission Research Branch in visits to Dornoch, Black Isle, and Teindland, Morayshire, to examine and sample problem areas where trees have failed in plantations. (e) Collaboration with the Colleges of Agriculture in selecting sites for field trials and in identifying soils, with other departments of the Macaulay Institute in obtaining representative soil and plant material for studies on clays, trace elements and organic matter, and with various other educational and research organizations.

A joint field meeting of the Surveys of England and Wales and of Scotland was held at Inverness from May 13th to 18th. Field excursions to examine the soils of the area were made to Wester Ross, Easter Ross and the Black Isle, and the southern coast of the Moray Firth. Members of the staffs of the North of Scotland College of Agriculture and the Forestry Commission were invited to address meetings and to accompany the party on some of the field excursions.

Dr R. Glentworth attended the meeting held in Dublin in June of the Soil Resources Committee of the F.A.O. Working Party on Soil Survey and Classification in Europe. Mr J. W. Muir attended a symposium on soil classification held in Ghent, Belgium; a week of lectures and discussions was followed by a tour of sites in Belgium and West Germany, where important soil types were demonstrated.

Although field work on Sheet 39 (Stirling) has been completed, much analytical work has still to be done. It is, however, possible to give a general account of the geology, soils, and agriculture of the district.

*Sheet 39 (Stirling)*

The area surveyed comprises some 430 square miles in the counties of Perth, Stirling, Clackmannan, Fife, and Kinross. The boundary line on the east runs from Auchterarder, Perthshire, through the Ochil Hills and West Fife to Culross on the Firth of Forth; on the south it runs from Culross via Denny to Fintry in Stirlingshire, on the west through East Flanders Moss to the slopes of Ben Vorlich, north of Callander, in Perthshire, and on the north from Ben Vorlich via Muthill to Auchterarder. The burgh of Stirling lies just south of the centre of the area and is the principal market town.

Two major regions of Scotland, the Highlands and the Midland Valley, are represented within the area. The latter is the more extensive and it can be subdivided into three morphological regions—(i) the Helensburgh-Stonehaven trough, (ii) the lava hills which confine the trough to the south, and (iii) the Carboniferous lowlands. The geological formations have been glaciated and this has resulted in the development of many distinctive soil parent materials, namely glacial tills, moraines and fluvioglacial

deposits. Post-glacial fluctations in sea-level have resulted in the formation of extensive raised beach deposits and spreads of marine alluvium; extensive accumulations of basin and hill peat also occur.

An important factor governing soil formation in this part of Central Scotland is the generally high rainfall. Although the area lies on the fringe of the east coast lower rainfall belt, the presence of the Ochil Hills and of the Fife hills to the east tends to minimize the effect of this proximity to the east coast, as the hills attract rain from both east and west, so that the district generally receives a fairly high rainfall in most years.

Average rainfall in the Lower Forth Valley is only 30 inches, but for the lowlands in this area it is between 35 and 40 inches; the hill areas have at least 50 inches per annum, and the higher lava hills and the highlands over 60 inches in an average year. The high rainfall, coupled with a high proportion of fine-textured parent materials and the tendency of coarser textured parent materials to produce an indurated horizon which impedes soil drainage, has produced an extensive development of surface-water gley soils and brown forest soils which are imperfectly drained and gleyed in the B and C horizons. A further effect of the high rainfall is the tendency for the accumulation of surface organic matter, and peat formation occurs at the relatively low altitude of 600 feet. Above this altitude the peaty podzol and peaty gley major soil groups dominate the soils and peat is widespread on the gentler hill slopes and summits.

The strong north-westerly, westerly, and south-westerly winds form another important element of the regional climate and most of the farmland suffers from exposure to some degree. In addition, the low-lying Carse of Stirling and the contiguous low-lying till plains suffer occasionally in the summer from east coast haar which considerably affects the crop growing season by reducing the temperature.

Seventeen soil associations, comprising 70 soil series, have been distinguished. Many of these series have been recognized in other regions of Scotland, particularly in Ayrshire, Aberdeenshire, Angus and, to a lesser extent, the Lothians and eastern Fife.

The following are the associations distinguished to date:

| *Association* | *Parent Material* |
|---|---|
| Balrownie | Till derived from Lower Old Red Sandstone sediments—mainly sandstones and flagstones—with some Highland erratics. |
| Callander | Mixed till derived from the Dalradian Series of Highland Schists and Lower Old Red Sandstone sediments. |
| Carbrook | High Raised Beach silts and clays. |
| Carse | Low Raised Beach silts and clays. |
| Darleith | Till derived from Carboniferous basaltic lavas and intrusions. |
| Darvel | Fluvioglacial sands and gravels derived from Carboniferous sediments, Old Red Sandstone lavas and some Highland Schist rocks. |

| | |
|---|---|
| Doune | Fluvioglacial sands and gravels derived from Highland Schist rocks with some Lower Old Red Sandstone sediments and lavas. |
| Dreghorn | Raised beach sands and gravels. |
| Dunblane | Till derived from Lower Old Red Sandstone sediments—mainly flagstones, mudstones and siltstones—with Highland Schist erratics. |
| Forfar | Periglacially modified till derived from Lower Old Red Sandstone sediments with some Highland Schist erratics. |
| Foudland | Till derived from slate and schists of the Dalradian Series of Highland Schists. |
| Gleneagles | Fluvioglacial sands and gravels derived from Lower Old Red Sandstone sediments and lavas with some Highland Schist rocks. |
| Kippen | Till derived from Upper Old Red Sandstone sediments with some Highland Schist erratics. |
| Kirktonmoor | Moraine debris derived from Carboniferous basaltic lavas and ash. |
| Rowanhill | Till derived mainly from Carboniferous sandstones and shales but with some coals and subordinate limestones often present. |
| Sorn | Mixed till derived from Calciferous Sandstone sediments and Upper Old Red Sandstone sediments. |
| Sourhope | Till derived from Lower Old Red Sandstone andesitic and basaltic lavas, agglomerates and tuffs. |

Although considerably modified by fairly severe glaciation, the regional relief is determined by the solid geology. The highest ground in the highlands is formed by the extremely resistant, highly metamorphosed Dalradian Series of Highland Schists which occurs north of Callander in the extreme north-west. The commonest rocks are slates and schists, but bands of grit and quartzite also occur. Summit levels are around 2,000 feet, with the 3,000 ft. mountains of Stuc à Chroin and Ben Vorlich immediately to the north. Rainfall over the high ground exceeds 60 inches per annum and approaches 75 inches, resulting in the extensive development of blanket peat which is frequently very thick on concave sites, and on the more exposed summits is often eroded. The peat carries an *Eriophorum-Calluna-Trichophorum* vegetation. The mineral soils are developed on till of variable thickness, derived from the slates and schists, and belong to the Foudland Association, with the peaty-topped Suie (peaty podzol) and Shanquhar (peaty gley) the commonest series.

Immediately south-east of the Highland Boundary Fault is a series of Lower Old Red Sandstone rocks forming the foothills of the highlands beyond the fault. Nearest the fault conglomerates and pebbly grits of Old Red Sandstone age are steeply folded, almost vertical, and form the highest

rounded hills with Uamh Bheag (2,181 ft.) and Beinn Odhar (2,072 ft.) the highest summits. South-eastward from the fault the Old Red Sandstone rocks form a broad syncline across the Middle Forth Valley and across Strathallan. The grits are succeeded by flaggy sandstones, mudstones, and siltstones which underlie the Braes of Doune and the moors on the north side of Strathallan. Much of the ground above 600 feet is moorland, with a good deal of hill peat up to the summits where erosion is active; 6 feet deep peat hags are frequent. The mineral soils on the lower slopes are dominated by the peaty-topped surface-water gley and its its better drained variants on which some reclamation and reseeding to grass have been carried out with fair success. The ground below 600 feet is generally drumlinoid in topography, formed from till derived mainly from the underlying rocks—flagstones, mudstones, and siltstones. Freely and imperfectly drained brown podzolic soils, frequently with well-developed indurated layers, are the dominant soil types, and they belong to the Dunblane Association.

The Teith Valley, running south-eastward from Callander to the Forth above Stirling, is flanked on both banks with terrace and fluvioglacial sands and gravels derived largely from Highland Schist rocks, with gravel dominant; the two are intermixed and it is very difficult to separate them as single mapping units. Small pockets of peat occur in hollows between eskers and gravel mounds, and occasional lenses of boulder clay, very fine sand and silt occur in gravel pit sections. The dominant soil type under trees is the podzol—usually a fairly well-developed iron podzol with a distinct leached $A_2$ horizon and a strong brown $B_2$ horizon. Under grass or bracken a brown podzolic type of profile is more usual. These soil types belong to the Doune Association.

The last glacial readvance in the Callander district resulted in the deposition of a mixed till derived essentially from the Dalradian Highland Schists and the underlying Old Red Sandstone sediments. This mixed till spreads out from the Leny gap, north of Callander, down both banks of the Teith, up to an altitude of approximately 400 feet, in an elongated tongue which terminates just short of Doune. To the south the area of mixed till extends across Lennieston Muir and into the broad Forth Valley, stopping approximately a mile north of Thornhill. The lithological content of the till is variable; near Callander it is dominated by the Highland Schist rocks, while further away it is dominated by Lower Old Red Sandstone rocks, mainly purple-grey sandstones. The topography south of Callander, around Lennieston Muir, is hummocky and moraine-like, but the soils differ little from those on the longer, gentler slopes in other areas where the mixed till occurs. Imperfectly drained brown podzolic soils are dominant, but iron podzols occur on some of the mounds and peaty podzols on low mounds within the peat on Lennieston Muir. Peaty-topped surface-water gley soils occur in some of the hollows and more depressed sites. All these soil types have been grouped into the Callander Association.

Strathallan is covered to a large extent by a spread of fluvioglacial sands and gravels at altitudes of between 200 and 400 feet. The alluvial floor of

the strath also tends to be gravelly, but irregular silty and peaty patches also occur; there is an important raised peat moss at Shelforkie near Greenloaning. The gravels are most extensive around Gleneagles, where they form the watershed between the Allan Water flowing west to the Forth and the Ruthven Water flowing east to the Earn. Again the sands and gravels are intimately intermixed and difficult to map separately. The gravel is dominant and is derived principally from the underlying Old Red Sandstone sediments, although Highland Schists and lavas are included in the material. Much of the ground is cultivated, but the dominant soil is a podzol. On older undisturbed sites peaty podzols with thin iron pan have developed, while under recently planted woodland podzolization is noticeably in progress. These soils belong to the Gleneagles Association.

North and east of Gleneagles the low ground forms the southern margin of Strathearn, with the Coire Odhar and Tullibardine moorlands forming the boundary further west. This low-lying ground is underlain by Old Red Sandstone sandstones and flagstones which have given rise to a comparatively fine-textured reddish brown till. Below an altitude of approximately 250 feet the surface of the boulder clay, in immediately post-glacial times, was modified by periglacial and fluvioglacial streams flowing along the complex system of glacial meltwater channels which occur in the area. The soils developed on the till, or on only slightly modified till, belong to the Balrownie Association.

The modified till is light-textured, almost sandy, often to a great depth, and gives rise to a very useful agricultural soil, especially in this lighter rainfall area where the presence of the moist unaltered till below tends to prevent excessive drying out in drought periods. These deep modified till soils belong to the Forfar Association. The dominant series in each association is a brown podzolic soil with some gleying in the B horizon and usually with a well-developed indurated $B_3$ horizon immediately above the till.

The moorland soils of Coire Odhar and Tullibardine belong to the Balrownie Association with the dominant series an imperfectly drained peaty podzol, generally with no development of iron pan, but with a strongly gleyed $A_2$ horizon and considerable gleying in the B horizon above the indurated layer. Small patches of peaty gley soils occur in the shallow hollows and peat is extensive over the higher parts of Coire Odhar.

The south-eastern limb of the broad syncline of Old Red Sandstone rocks forming Strathallan laps up against the Ochil Hills to the south. These hills consist of deep valleys and long ridges leading up to broad summit areas at an altitude of over 2,000 feet. The highest point is Ben Cleuch, 2,363 ft., and there are several summits above 2,100 feet. The andesitic and basaltic lavas and tuffs of Lower Old Red Sandstone age give rise to a very uniform soil parent material, a freely drained gritty loam. The only significant variation is the occurrence of a poorly drained moderately fine-textured till in the valley bottoms. Above these, slope and climate pay a dominant role in soil formation, a common upward sequence being: on the lower slopes brown forest soils with *Agrostis-Festuca* grassland, sometimes invaded by bracken, passing up through brown podzolic soils to iron podzols and peaty podzols,

often with iron pans, supporting Nardetum; on the shoulder of the hills a structureless peat, with tussocky Nardetum, which has apparently been washed from the ridge tops and summits where deep peat is found under Eriophoretum. The soils belong to the Sourhope Association.

The Carboniferous lava hills lying to the south of the Middle Forth Valley comprise the Fintry, Gargunnock, and Touch Hills. They consist of a vast sequence of basaltic lava flows of various types dipping gently towards the east to give an almost plateau-like upland area with its highest point, Stronend, rising to 1,677 feet at the western end. The separate lava flows form a series of shallow dip and scarp features and terraced hills in the upland area which in the north rises steeply in a series of lava cliffs from the Forth Valley; on the south the slope drops steeply into the Endrick and Carron Valleys. The basalt lava flows also give rise to a fairly uniform reddish brown till which appears to be widespread over the hills. A sequence of soils, very similar to that found on the Ochil Hills, is also found on the hill slopes here, but in addition there is a large expanse of *Eriophorum-Calluna-Trichophorum* moorland on peat and peaty podzol soils. In spite of the high rainfall there is a remarkable absence of gley soils on the hills. The dominant series is a peaty podzol, usually with a thin iron pan and some gleying above and below the pan, and a well-developed indurated layer immediately below the iron pan. These soils belong to the Darleith Association.

Moraines are present in the Endrick Valley, on Cringate Moor, and along the scarp faces of the Fintry and Gargunnock Hills. They are moundy deposits consisting almost entirely of lava fragments, but with some subrounded Highland erratics giving them a more gravelly appearance. The dominant series is a freely drained brown podzolic soil, although a more podzolized variant can be seen. These soils belong to the Kirktonmoor Association.

Between the Forth Valley bottom and the lava hills to the south a drumlin field extends from Kippen in the west to beyond Gargunnock in the east. It is underlain by three sets of rocks. Adjacent to the Forth, and underlying it, is a series of dark red and purple sandstones and mudstones of Lower Old Red Sandstone age which here, as north of the river, give rise to till soils of the Dunblane Association. To the south the Lower Old Red Sandstone rocks are succeeded unconformably by bright brick-red coarse sandstones of Upper Old Red Sandstone age, which give rise to a bright red till on which soils of the Kippen Association are developed. The Upper Old Red Sandstone rocks are succeeded conformably by grey and brown sandstones and cementstones of Calciferous Sandstone age on which is developed a very fine-textured till which is the parent material of soils of the Sorn Association. The dominant series of the Sorn Association is a well-developed surface-water gley with a tendency to the formation of an organic upper horizon. The lighter-textured parent material of the Kippen Association usually develops an imperfectly drained podzolic soil without iron pan and occasionally with a peaty top. Much of the arable land round Kippen and Gargunnock is the cultivated version of this imperfectly drained podzol.

The Carboniferous till plain of Stirling, Clackmannan, and West Fife is underlain by a broad syncline of Carboniferous sediments; these include sandstones, shales, coals, and subordinate limestones of the Carboniferous Limestone Series, the Millstone Grit Series, and Coal Measures, of Lower, Middle and Upper Carboniferous age respectively. Since in this part of Scotland each of these three divisions consists essentially of this rhythmic sedimentary sequence of sandstones, shales, coals, and limestones, the overlying tills are essentially similar in their main features; in detail, however, the tills show considerable variation from place to place, depending on which rock component of the sequence is dominant.

Both in Stirling and in Fife the Carboniferous Limestone Series of rocks tends to give rise to fine-textured greyish till, with more coal and shale in it, and the resulting soil is usually the poorly drained heavily gleyed Rowanhill series. The till overlying the Coal Measure strata, which include the red Devon Sandstone outcropping near Tillicoultry, is a purplish red-grey-brown colour, and although fine-textured it is not so fine as that over the Carboniferous Limestone rocks. The till overlying the Millstone Grit Series is of fine texture and purplish brown-grey in colour and is similar to that of the Carboniferous Limestone Series. The dominant soil over the Coal Measures is an imperfectly drained brown forest soil with gleyed B and C horizons, while that on the Millstone Grit Series of rocks is a poorly drained surface-water gley. These soils are grouped into the Rowanhill Association.

Several tracts of the Millstone Grit Series are drift free, notably Devilla Forest where coarse granular sandstones and grits outcrop at the surface. Soils developed on these sandstones are very coarse-textured, often almost pure sand and rotten rock. Under forest conditions the soils form well-developed iron and humus-iron podzols. They have a deep pinkish grey or ashy grey $A_2$ horizon, a well-developed humus B horizon and a less well-developed iron enriched $B_2$ horizon.

Associated with the Carboniferous tills are several spreads of sand and gravel, notably at Cowie, south of Stirling, and along the Devon and its tributaries between Dollar and Rumbling Bridge. The gravel content is very mixed and consists mainly of Carboniferous sediments, Old Red Sandstone lavas, and some Highland erratics. The soils developed on these gravels belong to the Darvel Association and the commonest series is a freely drained brown podzolic soil.

The raised beach deposits of the Forth Valley constitute some very important soil parent materials. Most important are the deposits of the Low Raised Beach, locally known as the Carse Clays, which make up the flat Carse of Stirling extending from East Flanders Moss in the west to Kincardine Bridge and Airth in the east. These deposits consist of a series of marine clays, silts, and, rarely, sands; layers of marine shells, including cockles, mussels, oysters, and periwinkles, have been found in many places. The parent material of the soils developed on these carse deposits is almost always a heavy silty clay or a clay-silt. The proportion of sand present is always less than 5 per cent., while the clay content may be as much as 70 per cent. and the silt as much as 55 per cent. It has been found that as a general

rule the percentage of clay is highest in western areas while the percentage of silt becomes highest towards the east. The dominant Carse Series is a well-developed ground-water gley with strongly developed prismatic structure. When wet the clay is massive and structureless, but on drying the material shrinks into very large almost perfect prismatic structural units. The carse clay soils are grouped into the Carse Association.

The High Raised Beach deposits are of two types, silts and clays, and sands and gravels, both occurring at altitudes ranging from 75 to 125 feet above sea level. The High Raised Beach silts and clays occur at approximately 75 feet, up slope from the Carse deposits, notably around Carbrook, Plean, and Bannockburn, south of Stirling on the south side of the Forth. There is another occurrence far to the west near Arnprior, again on the south side of the river. The silts and clays appear to be completely absent on the north side where the High Raised Beach deposits are sands and gravels with occasional lenses of very fine sand and silt; they occur around Thornhill, Airthrey Castle, and along the foot of the Ochil scarp between Logie and Menstrie, with smaller distributions around Clackmannan and Kincardine. Similar deposits are also found on the south side of the Forth between Bannockburn and Cowie, at the foot of Stirling Castle, near Tough House, and at Arnprior. The red clay deposits have been separated as the Carbrook Association where the dominant series is a poorly drained surface-water gley. The sands and gravels have been included in the Dreghorn Association where the dominant series is a freely drained brown forest soil of low base status.

The agriculture is progressive and highly mechanized; tractors, balers, combine harvesters, and all the other requisites of the up-to-date farmer are common. Most farms are of small to medium size with the farmer both manager and key worker, although there is a tendency for two or more of the smallers farms to combine into a larger unit. While many farms are rented and some families can trace their tenancy of the same farm for considerably over a century, there has of late been an increase in owner-occupiership, both by the purchase of farms by tenants and by estate owners taking farms into their own management.

Central Scotland has long been famous for its stock. In the past it has figured prominently in the breeding of Clydesdale horses. There are first-class dairy herds of Ayrshire and Friesian cows, and some of the beef herds of Aberdeen-Angus and Shorthorn cattle have a world-wide reputation. A number of herds of Highland cattle are being built up on hill farms. Many marginal farms rear beef stores, and hill farms have developed a method of cattle rearing involving hardy cattle, mainly Shorthorn crosses, which can be out-wintered. Though the progeny of this stock mature rather slowly, they make excellent beef. The most important sheep is the Blackface, but there are also some good flocks of Border Leicesters which are sold for crossing with the Blackface. The pig population has increased recently and deep-litter poultry-keeping is important.

The climate is suitable for growing wheat, barley, and oats, and beans are becoming an important crop throughout the area, although they have long been grown on the Carse of Stirling. Turnips are widely grown and silage production is also important and increasing. Potatoes are grown for both ware and seed. The Carse of Stirling is noted for timothy hay and for Scotch timothy seed, and timothy hay is now often grown in West Fife. Throughout the area grass is probably the most important crop.

The agriculture reflects the great diversity of soils, and agricultural practice on each farm is strongly influenced by the soils occurring there. The Carse of Stirling is perhaps the best example of farm practice related to soil type (Carse series), with the pattern of farming almost unique in the district and indeed throughout Scotland.

The Carse series is essentially a heavy-textured gley soil, massive and sticky when wet, but developing, when dried out a little, a good prismatic structure which allows moisture to drain slowly away. No hard and fast rotation is adopted nowadays, but a good rotation is lea oats, followed by winter wheat, beans, oats (or barley), green cut timothy hay, seed timothy for two years, followed by green cut timothy hay for three years. Green cut timothy in the past was often left in the rotation for up to fifteen years, but is now rarely retained longer than seven years. Prior to breaking grassland many farmers undertake mole draining. Fallow is less common than formerly, and as a result of continuous cropping there is a tendency for land to become infested with couch grass. Mechanization has enabled many carse farms to utilize the former fallow break, which usually preceded wheat in the rotation, for a crop of turnips. If turnip land is properly cultivated it can be kept clean and so accomplish the same object as fallow and provide additional feeding for stock.

The heavy silty clay texture of the Carse series makes it difficult to work. Land worked when conditions are not suitable can be disastrous to soil structure, so that timing of cultivations is a major factor. Assisted by disc and harrow, the plough is still the most important implement. Considerably more time and effort are required for the production of a good seed-bed on the carse clays than on soils elsewhere in the district. In some seasons the land may have to be ploughed up to ten times and broken down between ploughing operations by harrowing and rolling before a reasonable tilth is obtained. It is the high cost of cultivation of the soil which largely determines the main crops of the Carse of Stirling, those crops being grown which give a high yield per acre in return for minimum cultivation. Timothy hay once sown-out requires little cultivation; many farmers harrow the stubble annually to keep the land clean and the plants vigorous. Grain crops are also important, requiring less cultivation once sown.

For many years the Carse series has produced excellent crops, mainly with the help of farmyard manure and comparatively heavy dressings of sulphate of ammonia. Increasing the application of phosphate and lime has shown, however, that yields can be profitably increased by more balanced manuring. Nowadays a good average yield of timothy hay is nearly 4 tons per acre,

while average yields for grain crops are 35 cwt. per acre for wheat, 33 cwt. per acre for oats, and 30 cwt. per acre for barley.

Arable land other than carse land in the Stirling district is usually referred to as " dryfield." This can be separated into three units according to the underlying rocks. The first and most extensive of these comprises the Lower Old Red Sandstone rocks of Strathallan and the ground north of the Forth between Thornhill and Dunblane. The dominant soil series are the freely drained Dunblane series, a brown forest soil of low base status, and the imperfectly drained Kippendavie series, a brown forest soil with gleyed B and C horizons with a high base saturation.

Dairying is of minor importance in this part of West Perthshire. Some farms changed to dairying during the last war, but there has been a tendency to revert to the traditional systems of rearing and feeding beef cattle and growing seed potatoes. West Perthshire is noted for the production of seed potatoes and this is one of the most important cash crops. A high proportion of the seed is of stock seed standard. Other important crops are wheat, oats, turnips, and grass. The soil is fairly easily worked and with the help of fertilizers, especially lime and phosphate, produces good crops. Average yields are slightly lower than on the Carse of Stirling, but rye-grass hay will yield 3 tons per acre, wheat 30-35 cwt. per acre, and oats 30-35 cwt. per acre. The new oat variety, Condor, will yield over 2 tons per acre on these soils. Turnips are important as stock feed.

The gravel soils of the Gleneagles Association in Strathallan suffer from drought in a dry season; turnips and potatoes are particularly affected and therefore tend to be less important in this area where grass and grain crops are more in evidence. Farms being small and irrigation expensive, this method of ensuring an adequate water supply for crops has not yet been introduced. Irrigation is, however, a possible future development, since it has been introduced successfully on some farms around Perth to the east.

The crops growing on the sandier Old Red Sandstone soils of Strathallan and the stock grazing on the grass have in recent years occasionally shown the effects of copper, magnesium, and manganese deficiency. These deficiencies do not seem to be general, and in these cases are thought to have been induced by over-liming.

The second and smallest unit of " dryfield " soils is that underlain by rocks of the Upper Old Red Sandstone age. These Upper Old Red Sandstone soils of the Kippen-Gargunnock area of Stirlingshire are particularly low in plant nutrients and need a considerable amount of fertilizer and farmyard manure to produce good crops. The pattern of farming is similar to that of Strathallan, but with steeper slopes grass is more dominant and stock rearing for beef correspondingly more important.

The farming pattern of the Carboniferous " dryfield " soils of Stirlingshire, Clackmannan, and West Fife may be suitably described according to the county. In Stirlingshire the dominant soils are clay-textured and are derived either from the High Raised Beach clays (Carbrook series) or from Carboniferous till of the Rowanhill Association (Caprington and Rowanhill

series). Dairying is important on these soils and there are notable Ayrshire and Friesian dairy herds. Grass is the most important crop, but grain is also grown, these two crops being best suited to the clay-textured soils. The sandy beach and gravelly soils around Cowie are utilized for potatoes, turnips, and grain, with grass as a less important crop in the rotation.

In Clackmannanshire both underground and surface coal-working operations have caused damage to agricultural land. Surface operations ceased some ten years ago, but the effects of bad restoration and bad drainage can still be seen. Recent new drainage schemes and reseeding to grass should bring about considerable improvement. The dominant soil is the imperfectly drained Winton series of the Rowanhill Association which, with suitable fertilizer treatment, grows excellent crops, notably barley, oats, wheat, potatoes, and turnips. Mixed farming, with dairying important, is typical of the county.

West Fife suffers from a higher rainfall than the rest of the Carboniferous till plain, so that the dominant, poorly drained, Rowanhill series is unsuitable for growing anything but grass. Dairying and stock rearing for beef are important aspects of the farming pattern. Drainage of these heavy-textured soils is difficult; the heavily gleyed surface horizons prevent water percolating down to the tile drains and cause surface water-logging on flat and depressed sites. Rushes become a considerable nuisance and fields have to be reseeded fairly frequently. Arable farming is practised where the better drained Caprington series occurs and on the lighter beach and gravelly soils flanking the Forth estuary and the Bluther Burn. The main crops are barley, oats, and some wheat, potatoes, turnips, and some sugar beet.

The lava hills—the Ochil, the Fintry, the Gargunnock, and the Touch Hills—provide rough hill grazing for sheep and cattle. Hill farms are large but grazing densities are not heavy. Sheep are most numerous, but cattle are becoming important on the marginal land and lower hill slopes. On the better grazings of the Ochil Hills, underlain by Frandy series (podzol) and Cowie series (peaty podzol), the density is 2 sheep to 3 acres; the poorer parts, on hill peat, carry only 1 sheep per 3 acres. Similar densities occur on Baidland series (peaty podzol) and on hill peat in the Gargunnock Hills.

The Old Red Sandstone hills, above Braes of Doune and Strathallan, carry fewer sheep and the average density over this whole hill area is probably only 1 sheep per 3 acres of hill. The higher base status of the lava soils no doubt accounts for the better carrying capacity of the lava hill grazings.

Some reclamation by ploughing and reseeding to grass has been carried out round Severie (900 ft.) on Braes of Doune and near Biggs (950 ft.) on Sheriffmuir. Good grassland was successfully established on peat and peaty podzol soils at Severie and on a well-developed podzolic soil at Biggs. In both cases heather and rough grasses have been replaced by good grass which has been maintained as such for a number of years to date. Reclamation is expensive but well worthwhile and becomes profitable after a few years. There is scope for much more of it on these marginal and hill grazings.

The co-operation and encouragement of the West of Scotland Agricultural College county advisory officers in Dunblane and Stirling has been invaluable during the course of the survey. Farmers and landowners, too, have shown great interest in the survey, and their assistance has been much appreciated.

## SPECTROCHEMISTRY

The full benefits of the new laboratories occupied during 1961 are now becoming apparent. The more adequate accommodation has enabled better use to be made of the available equipment and new techniques to be developed at a greater rate.

Increased facilities can now be offered to visiting research workers following the restrictions which have had to be imposed during the past years. Dr M. M. Guha from the Rubber Research Institute of Malaya, Miss Beate Berner of the Statens Rastofflaboratorium, Trondheim, Norway, Mrs M. F. Siroki, Institute of Metallurgy, Sisak, Yugoslavia, and Mr D. J. David of the Australian C.S.I.R.O. Division of Plant Industry, Canberra, have spent extended periods in the department, and workers from Ceylon and the United Arab Republic have made shorter visits to study techniques. Dr M. M. Guha's thesis on *The trace element uptake of deciduous trees* was accepted by the University of Aberdeen.

Dr R. L. Mitchell attended the International Conference on Spectroscopy in College Park, Maryland, in June 1962, a meeting attended by over 800 workers from some 20 countries, and took the opportunity of visiting in Ottawa the Soils Research Institute and spectrographic and other laboratories of the Geological Survey of Canada. Dr Mitchell, a member of the international organizing committee, attended the Fourth Colloquium on Plant Analysis and Fertilizer Problems in Brussels in September 1962, and also the International Feigl Symposium in Birmingham in April 1962. Dr Scott lectured on spectrochemical techniques at the Summer School in Analytical Chemistry in Manchester organized by the Royal Institute of Chemistry. Other members of staff attended meetings of various scientific and official organizations in Great Britain.

*Trace Elements in Soils, Plants, and Biological Materials*

*Soils and Soil Parent Materials.* Soils of the area discussed in the Soil Survey Memoir covering eastern Aberdeenshire[32] have been examined for total and extractable trace elements. This is an area of exceedingly varied soil parent materials and numerous instances of deficiencies or excesses occur. Cobalt deficiency in stock is liable to arise on soils of several associations derived from Old Red Sandstone (Hatton, Ordley), quartzite (Durnhill), fluvioglacial or raised beach (Fraserburgh, Blackwater) or even gneissic (Countesswells) parent materials. Copper deficiencies in cereals can generally be related to the Ordley and Hatton Associations or to certain Countesswells soils. Molybdenum excess in stock may be found in some poorly drained soils of the Foudland or Tarves Associations in the valley of the Ythan, and nickel excess may limit crop growth in small areas on the Tarves and Leslie Associations influenced by ultrabasic parent material and impeded drainage.

Further work is in progress on the distribution of trace elements in soil profiles, particularly regarding the nature of the extractable trace elements in surface soils. The relative amounts of different trace elements extracted

by different reagents, for instance acetic acid, ammonium acetate or ethylene-diamine-tetra-acetic acid (EDTA), vary very markedly from element to element and from horizon to horizon, and it would appear that the results might provide some indication of relative plant availability.

*Soil Status and Plant Uptake.* The long-term study of cobalt uptake by pasture herbage species carried out in collaboration with the department of Soil Fertility has already produced some interesting findings, and preliminary results have been presented[38]. It has, for instance, been shown that even on lime-rich soils cobalt sulphate is a more efficient additive than the EDTA-cobalt chelate, and that on such soils the effect of cobalt can persist for at least three years, although a somewhat higher rate of application may be required than on acid soils. It also appears that the effects of cobalt application persist longer in clover than in grasses. Other collaborative investigations on copper, manganese, and molybdenum uptake are in progress.

A number of plant samples of varied species have been analysed for several biologically important trace elements in connection with the investigation of the relationship between mineral composition of plants and the cation exchange capacities of their roots being carried on jointly by the departments of Soil Fertility and Plant Physiology. This work is continuing.

The analysis of a complete Scots Pine tree, which had to be suspended for a period during the preparations for removal, has been resumed, and determinations of silicon, aluminium, and boron are now being made. The work carried out on the trace element contents of the soils and vegetation of the Island of Rum on behalf of the Nature Conservancy in collaboration with the Soil Survey of Scotland has now been completed and a report submitted to the Conservancy. The results suggest the possibility of cobalt deficiency in ruminants on a number of soils in the north part of the island.

Typical of various samples analysed on behalf of other organizations are a series of sugar cane samples from a trace element experiment laid down by the British Honduras Department of Agriculture. In such collaborative work it is always desirable to have, as in this instance, prior consultation with the workers in the field, who may not appreciate fully the implications of sampling for trace analysis or the laboratory work involved, and in consequence design an experiment involving an impracticable number of samples. On occasion, several thousand samples per experiment have been suggested, although in our own trace element work the number of samples per annum per field experiment is normally kept well below 100.

The trace element content of arable soils can be affected by various agricultural operations, and it is useful to know whether any of the fertilizers employed to supply major plant nutrients normally contain sufficient of any of the trace elements to have a significant effect on the trace elements status of the soil. A survey of the literature, covering the contents of over 60 elements in N, P, and K fertilizers, liming materials, organic manures, and miscellaneous additives including industrial wastes, slags, and soil amendments, made by Dr D. J. Swaine before he left the Institute staff, has now been published[7]. In general, the commonly used fertilizers would not be expected to affect the trace element status significantly.

*Spectrochemical Methods of Analysis*

There has been a 50 per cent increase in the number of samples analysed for trace elements during the year, attributable mainly to improved laboratory facilities for chemical concentration and pretreatment. Demands for magnesium determinations from other departments have fallen slightly, but still average almost 40 per day with occasionally more than double that number—a demand that can readily be met by direct reader, employing the porous-cup solution-spark technique. The requirements of other departments for determinations of potassium, sodium, and calcium by flame photometry have been maintained on a level similar to that of previous years. A general account of the methods at present being employed, including a description of certain of the features incorporated in the new laboratories to minimize contamination, has been presented to the Feigl Anniversary Symposium[39].

*Arc Emission.* No significant changes in the cathode layer arc excitation technique have been introduced. This is still the basic method for the semi-quantitative examination of soils or soil parent materials, and for the quantitative determination of most of the biologically important trace elements in soil extracts or plant materials, generally after chemical concentration. The technique is in fact fundamentally unchanged from that introduced almost 20 years ago. It is convenient for the simultaneous determination of a number of elements; if only one element is required, a specialized technique covering that element alone may be preferable, particularly if the somewhat time-consuming chemical concentration technique can be eliminated. As there is a continuing demand for the determination of cobalt in soil extracts, the possibility of developing such a method specifically for this purpose has been considered, and the atomic absorption technique described below is at present being tried out.

*Flame Emission.* The experimental three-channel flame photometer built in 1949 for the simultaneous determination of potassium, sodium and calcium has now been completely rebuilt. It is based on a Lundegardh-type sprayer and burner unit, the only major modification being the fitting of a baffle immediately in front of the atomizer orifice to reduce the proportion of larger droplets introduced into the flame. Both air and acetylene supplies are monitored by pressure gauges and flow-meters, as a pressure gauge alone can give a somewhat misleading indication of the gas supply rate in the event of a change in jet aperture. Calcium and sodium emissions are determined after isolation at exit slits by a Hilger wavelength spectrometer, Cambridge spot galvanometers being fed directly from 931A photomultipliers. Potassium emission (7665-7699A) is isolated by means of a set of filters (Chance 0N20, Ilford 207, and Barr and Stroud Interference Filter), converted to green fluorescence by a CV147 image converter, and measured by a 931A photomultiplier and spot galvanometer. This arrangement has proved reliable and given as satisfactory service as the chopped beam-exit slit-1P21-tuned amplifier arrangement for potassium in the research three-channel flame photometer which has been in use during the past year.

*Direct Photometry.* Both the Hilger Medium Direct Reader and the two-channel attachment built for the Hilger Small Quartz Spectrograph have given satisfactory service throughout the year, having required no more than a normal amount of electronic servicing. It is, however, always advantageous to have available someone capable of diagnosing and dealing with such minor faults as do arise. In the controlled temperature conditions prevailing in the new laboratories, the effect of atmospheric pressure variation on the calibration of the Medium Direct Reader has become more apparent than formerly, particularly for elements determined at short wavelengths, and a check on prevailing pressure is undoubtedly desirable before measurements are made if a prism type direct reader without pressure compensation is being used.

An account of some of the techniques employing a direct-reading measurement[8] has now been published. The porous-cup solution-spark technique for the determination of EDTA-extractable copper in soil has been used this year for over 1,000 samples where plant or animal deficiency was suspected. It has been found that the improvement in copper blank level observed after transfer into the new building, mentioned in the preceding report, has persisted throughout the year. It has proved necessary to maintain constant vigilance to avoid the introduction of sources of metallic contamination.

Porous-cup solution-spark excitation has been employed for the determination of a number of other elements, for instance zinc, manganese, aluminium, and iron. The results of some collaborative investigations with the departments of Microbiology and Biochemistry on the bacterial breakdown of minerals are awaiting publication[40], and other similar collaborative work is in progress.

The development of the rotating pressed-disk technique for the examination of plant ashes and dry matters has continued, with particular reference to the determination of boron, silicon, and aluminium. Attention has been drawn[39] to the dangers of boron contamination during sample or disk storage. There appear to be difficulties in obtaining reproducible excitation of silicon unless a rather vigorous triggered A.C. arc discharge is employed.

*Atomic Absorption.* A unit designed particularly for the determination of cobalt in soil extracts has been constructed during the year. This is based on the monochromator of the H700 Hilger Uvispek Spectrophotometer, with Hilger hollow cathode lamp and burner (using air-butane mixture) and a modified EEL atomizer fitted with a baffle plate to reduce intake of large droplets. The lamp is operated at 100 cycles and the output from a 1P28 photomultiplier is fed to an A.C. amplifier as designed by Box and Walsh. This set-up enables cobalt levels as low as 0·2 p.p.m. to be detected, and preliminary results indicate that it can be successfully employed to determine cobalt in dilute acetic acid extracts of soils following destruction of organic matter by nitric acid and dissolution in hydrochloric acid, the final volume of 5 ml. containing the extract from 20 g. soil. It appears possible to make allowance for the relatively high and variable calcium contents of the soil extracts by introducing aluminium.

*Absorption Spectrometry of Soil Constituents*

The clay fractions from a number of Scottish profiles being investigated in the department of Pedology have been studied by infrared techniques, and the information obtained has shown that infrared examination must take its place beside X-ray and differential thermal methods as an important tool in the characterization of soil clays. The infrared spectra confirm conclusions from differential thermal analysis that highly hydrated allophane-like components are often present in soils in considerable amounts[28]. In addition, the spectra indicate that amorphous silica, which is not easily distinguished by any other technique, is widely distributed in clays. In the group of crystalline clay minerals, infrared examination can assist X-ray studies in distinguishing kaolin minerals in the presence of chlorites.

The present lack of detailed studies on the infrared spectra of pure clay minerals limits the information which can be drawn from soil clay spectra. As with X-ray examination, valuable additional information can be obtained from changes in infrared spectra following heat treatment or the formation of clay-organic complexes. A collaborative study[27] of the dehydroxylation of layer silicates at temperatures up to 800°, and the subsequent rehydroxylation of the anhydrous products in steam has been undertaken with this end in view. The observation that montmorillonite undergoes a structural rearrangement to yield a rehydroxylate whose infrared spectrum resembles pyrophyllite may be of value in distinguishing this clay mineral. Work is continuing on the infrared absorption arising from adsorbed and constitutional water in clays, and on their distinction by their relative stability to heat treatment.

A collaborative study of some natural and synthetic aluminium and ferric phosphates by infrared, X-ray, and differential thermal methods has been completed[25]. The results serve not only to distinguish the different crystalline species in pure form and in mixtures, but also provide information on the degree of crystallinity of these materials, which is an important consideration in studies on their availability to plants and micro-organisms.

The installation of a Unicam SP.700 recording spectrophotometer, covering the wavelength range from 185m$\mu$ to 3·5$\mu$ has greatly facilitated the production of ultraviolet and visible absorption spectra, for instance in connection with the examination of plant extracts on behalf of the department of Biochemistry. It has also been employed in studies on the microbiological metabolism of lignin and related compounds proceeding in the department of Microbiology. It has relieved some of the pressure on the infrared spectrometer whose range (2$\mu$ to 15$\mu$) it overlaps in the near infrared. Other samples which have been examined on behalf of other Institute departments include plant materials, pollens, sugars, soil organic matter fractions, and several mineral species.

In all, nearly 3,000 infrared, ultraviolet, and visible spectra have been recorded during the year. A study of the origin of anomalous hydroxyl absorption in the alkali-halide pressed disks used in the infrared examination of solid samples has now been published[9].

## BIOCHEMISTRY

It was reported previously (Ann. Rep. 1958/59) that one effect of iron-deficiency on mustard plants was to depress the activity of the enzyme *aconitase,* as measured in extracts of the leaves. If iron was given to the plant the aconitase activity was restored in a few days to its normal level, but the addition of iron to extracts from iron-deficient leaves had no effect, so that it seemed that iron was required for the formation of the enzyme, not simply for its action. Iron might thus be an essential part of the structure of the enzyme molecule, or might be needed in one of the systems which synthesize it.

In the hope of deciding between these alternatives purification of the enzyme was attempted. Like many enzymes it is unstable at room temperature in the crude extracts made by grinding leaves with aqueous-buffer solution, and so all operations were carried out in a cold room. Many of the contaminating impurities of small molecular weight were left behind when the enzyme was precipitated by addition of ammonium sulphate to a high concentration. The ammonium sulphate was held back when a solution of the precipitate was passed through a tube loosely filled with material with pores which accept the small molecules of this salt, but not the much larger molecules of the enzyme. Finally the enzyme, still mixed with other proteins from the leaf, was passed in solution through a column of chemically-modified cellulose powder, for which the components of the mixture have different affinities. The portion of the fluid leaving the column which contained aconitase activity was collected for examination.

In contrast with the dark green extract from which it originated the fluid was colourless and water clear, and it contained only about one-hundredth as much protein for each unit of enzyme activity. It contained so little iron that it is extremely unlikely that this could form part of the structure of the active molecule. Substances which combine strongly with iron had no effect on its activity, and the addition of iron did not increase it, so it is tentatively concluded that iron plays no part in the composition or action of this mustard leaf enzyme but only in the process by which it is synthesized.

Experiments on the relationship between malic acid and calcium in the leaves of plants have been continued, and the results described in last year's report have been accepted for publication[41].

Examination of fresh material from many plant species has shown that the sugar *apiose,* previously known mainly from its occurrence in the glycosides of parsley, and in the polysaccharide fraction of a single species of marine flowering plant, is in fact widely distributed, and may often be a minor constituent of plant polysaccharides.

*Microbial Metabolism.* The results of the collaborative work with the department of Microbiology have been published[10, 11], in particular a full account of the study of microbial decomposition of minerals[40], described

in last year's report, in which the department of Spectrochemistry also participated.

*Soil Organic Matter.* A more complete analysis of the products of alkaline nitrobenzene oxidation of humus substances has been obtained as a result of improvements in the technique previously used (Ann. Rep. 1957/58); a paper on this subject has been prepared. In a rather different approach to the same basic problem the products of oxidation of methylated humic acids and related substances are being separated and identified by gas chromatography. By this method veratric acid and trimethylgallic acid, which escaped detection earlier (Ann. Rep. 1956/57), have now been identified.

A paper on the identification of two methylated sugars in polysaccharides from soil and peat[12] has been published.

The department has been fortunate in having two visitors working in it during most of the year: a Rockefeller Fellow in Agricultural Science, Dr W. Mysków from the Institute of Soil Science and Plant Cultivation, Pulawy, Poland, and Dr N. E. Nissim from the National and University Institute of Agriculture, Rehovot, Israel, holder of a Lord Simon Marks Scholarship for post-doctorate research in the U.K. Both have been studying aspects of the decomposition of organic matter in soils, and reference will be made to their results in the next annual report.

# PLANT PHYSIOLOGY

In mid-September 1962 removal to laboratories in the new Institute building was completed and a new stage in the development of the department has begun. Whereas formerly all the analytical work had to be done in one laboratory, the improved accommodation provides for specific operations being carried out in laboratories designed for the purpose. This will permit of greater precision in the use of existing techniques and enable the development of new techniques hitherto precluded by lack of adequate facilities. The section of Radioactivity, which from the first has had to operate under the handicap of shared accommodation, is now separately housed.

Dr A. K. Gaafar, an International Atomic Energy Authority Fellow of the U.A.R., spent a year in the department studying radioactive and other analytical techniques. Dr P. C. DeKock read papers at the International Symposium on Humus and Plant at Prague in October 1961 and at the Fourth International Symposium on Salt Absorption by Plants held at Pisa and Florence in April 1962.

*Interaction between Major and Trace Elements.* Excess of manganese or phosphorus, lack of iron, and high potassium-calcium ratios in leaves of plants all cause chlorosis. A detailed statistical study of the variation of the phosphorus-iron, manganese-iron, and potassium-calcium ratios in plant leaves has shown all these ratios to be interrelated. Moreover, statistical examination of published work by other research workers, purporting to show that these ratios are not always criteria of chlorosis, has provided evidence of relationships with chlorotic symptoms[42].

Further evidence for the metabolically linked variation in the phosphorus-iron and potassium-calcium ratios of plant leaves has been obtained from mustard plants grown in progressively diluted nutrient solutions[43]. In agreement with results obtained by earlier workers, who were, however, unable to advance any explanation for the phenomenon, it was found that dilution of the nutrient solution causes increased uptake of calcium and iron and decreased uptake of phosphorus and potassium, so that the phosphorus-iron and potassium-calcium ratios always show similar trends. In collaboration with Dr A. K. Gaafar, much of the above investigation has been repeated and extended, using the sweet potato plant, but the analytical work is as yet incomplete. Work on the growth of tomato plants in peat, in collaboration with the department of Pedology, is likewise awaiting attention in the new laboratories. A paper on the effects of natural and synthetic chelating agents on plant growth[13] has appeared.

*Ion Transport in Storage Tissue Slices.* Using radioisotopes of chlorine and bromine it has been shown that the time-course of anion uptake at 0°C by potato slices incubated at 25°C follows a two-component absorption pattern, the steady-state uptake being preceded by an initial period of more rapid absorption extending over the first hour. This initial phase is characterized by a specificity for any given ion or ionic species, e.g., chloride uptake is competitively inhibited by bromide but not by sulphate or

phosphate. The evidence suggests the possibility that the biphasic uptake pattern reflects the filling of absorption sites in the cytoplasm followed by a steady-state vacuolar penetration[44].

The possibility that the initial rapid phase of anion uptake results from a carry-over of a high rate of respiration from 25°C to 0°C has been investigated using an oxygen cathode. This is the first recorded use of this method to measure plant respiration at 0°C.[45] It has been shown that potato slices have a high oxygen affinity and that the respiration rate adjusts to the level characteristic of the low temperature within two or three minutes.

Results obtained from experiments investigating the rate of ion uptake at 0°C as a function of external concentration have been analysed in terms of the electrochemical potential gradient across the cell membrane. The concave absorption isotherm characteristic of chloride uptake from potassium chloride solution at 0°C closely follows the passive flux predicted on the basis of the potential difference across the membrane at different external concentrations. The concave upward curve results from a decrease in negative potential with increasing external concentration such that the electrochemical potential gradient—the real driving force on passive ion movement—increases more rapidly than the external concentration. Conversely, in calcium chloride solution an increase in external concentration causes an increase in negative potential and the chloride absorption isotherm follows the predicted convex shape. This work has been done in collaboration with the Department of Biophysics of the University of Edinburgh.

*Cation-exchange Studies of Plant Material.* The work on cation-exchange capacity (C.E.C.) with the department of Soil Fertility has been broadened in scope. A test has been completed of the C.E.C. and related uronic acid content in different organs of the same plant for a large range of species. The relationships between C.E.C. and mineral composition found for roots, stems, and leaves have been investigated for seeds and pollen. The number of species of lower plants examined for C.E.C. and chemical composition has been extended to over 400 in order to have coverage sufficiently representative to draw valid conclusions. Two papers on preliminary phases of the work [14, 15] have now been published.

*Radioactivity*

The description of an improved apparatus for the placement of radioactive isotopes in field studies of roots[5] has been published. The apparatus has been used extensively on various field experiments of the section of Peat Ecology.

Soil phosphate studies, in pot experiments, have been continued with the department of Soil Fertility, and a considerable amount of earlier work has been prepared for publication. This covers information on growth experiments in pots and estimates of phosphate status by conventional and radiochemical methods for a range of 40 soils.

Radiocarbon has been used by the department of Biochemistry for the study of transformation of organic matter in soil and for labelling citric acid to follow metabolic changes in plant leaves.

# MICROBIOLOGY

The general aims of the work of the department continue to be those outlined in last year's report. Collaboration with the departments of Biochemistry, Soil Fertility, Spectrochemistry and Pedology in many of the investigations has been maintained.

During the year Dr D. M. Webley gave, by invitation, a lecture on soil micro-organisms and difficultly soluble minerals to the British Society of Soil Science. Dr Moira E. K. Henderson attended the Eighth International Congress for Microbiology in Montreal, Canada, during August 1962, and read a paper.

In mid-September 1962 the department moved into its accommodation in the new building. Separate laboratories are now available for bacteriology and mycology together with the necessary ancillary rooms for media making, sterilizing, incubation, cold storage, and photomicrography.

*Phosphate-dissolving Micro-organisms.* Attention has been given to the phosphate-dissolving micro-organisms in the root region of three grass strains (Ryegrass S23, Timothy S50, and Cocksfoot S143). The grasses were grown in pots in the greenhouse and also sampled from the North of Scotland College of Agriculture Grassland Experimental Centre at Muchalls, Kincardineshire. At various stages in the growth of the plants the predominant micro-organisms were isolated from the root region of all the grass strains and the isolated organisms tested for ability to break down inorganic and organic phosphates. Breakdown of inorganic phosphates was investigated using the dicalcium phosphate plate technique developed in the department. A detailed account of this technique[16] was published during the year. A plate method using phenolphthalein phosphate has been investigated as a quick means of detecting organisms which can hydrolyse organophosphate compounds. The indicator phenolphthalein, which is released on hydrolysis by the organisms, gives rise at alkaline pH to a red colour. Also, this technique has been placed on a quantitative basis for liquid cultures. In addition, the breakdown of organo-phosphates is being investigated by determining inorganic phosphate released into the culture medium during growth of the organisms. This latter work, which is being carried out in collaboration with the department of Soil Fertility, is to be continued.

A note describing the method for the study of localized microbial activity in soil[11], reported last year, has been published. Further confirmation of the production of 2-ketogluconic acid in the vicinity of pellets containing glucose, when the latter are buried in soil, has been obtained. Improvements and modifications of the technique are now under investigation in an attempt to evaluate the factors controlling the localized breakdown of soluble substances, etc., in soils.

*Soil Micro-organisms and the Weathering of Minerals.* The ecological study of the microbiology of rocks with increasing degree of colonization by

lichens, etc., and of weathered stones has continued. Further work has confirmed the increase in numbers of bacteria and fungi obtained with increasing colonization of rocks. Suitable specimens for this study were obtained from Clachnaben, Kincardineshire, and from Ben Newe (Glenbuchat), Bennachie, Craig-na-Slice (Glentanar), Birk Hills, and Craggan (Ballater), Aberdeenshire, by members of the department of Soil Survey. In addition stones, showing varying degrees of weathering, found in quarries, profiles, gravel pits, etc., were examined. Bacteria, actinomycetes and fungi were detected in the interior of stones which were porous. No organisms were found in the interior of the unweathered stones so far examined. Over 400 isolates obtained from the above specimens were examined for their ability to break down silicates by the plate method developed in the department. Among the isolates those capable of producing 2-ketogluconic, citric and oxalic acids proved to be the most powerful dissolvers of the silicates tested. A paper describing this work[46] has been accepted for publication.

A detailed account of the influence of 2-ketogluconic acid-producing soil bacteria on minerals and related materials[40], reported on last year, is in the press. A further paper describing results obtained with fungi is being prepared for publication.

*Lignin Decomposition.* This work has continued with an attempt to study the breakdown of *a*-conidendrin and *a*-conidendrol, which have a lignin-like structure. Enrichment experiments using these substances have been carried out to isolate fungi which may be capable of decomposing lignin. Preliminary results based on ultraviolet and paper chromatographic analyses of culture solutions indicate that these compounds can be decomposed by some fungi. It is hoped to continue this work with similar compounds as they become available.

Many of the fungi, which have been isolated in the past in connection with the work of lignin breakdown, have now been freeze-dried for easier maintenance.

*Mineral Metabolism of Soil Nocardias.* The study of the physiology of iron-, zinc-, and manganese-deficient cells of *Nocardia opaca* was continued in collaboration with the departments of Biochemistry and Soil Fertility. One of the interesting features of this investigation was the discovery of decreased deoxyribonucleic acid (DNA) synthesis in the organism under manganese-deficient growth conditions. In earlier work from this department it was shown that *N. opaca* produced filamentous forms which failed to fragment in the normal manner when grown under manganese deficiency. In the light of these observations it appears that under conditions of manganese deficiency the production of filamentous growth is caused by failure of normal DNA synthesis in the cells. A detailed account of this work[10] has been published.

## SOIL FERTILITY

The main objective of the research programme is to clarify the significance of pedological factors, soil properties, and environmental conditions in relation to crop production and manurial practices, and to develop and calibrate laboratory methods for evaluating soil nutrient status. The experimental approach therefore continues to be concurrent development and integration of field, pot, and laboratory investigations covering the main agricultural crops and major soil types.

In addition to characterizing the behaviour of the different soils and crops with respect to the immediate and residual effects of lime, fertilizers, and farmyard manure on the yield and mineral composition of produce, the field programme is arranged to provide also direct answers to the practical manurial questions of rate, form, time, frequency, and method of application of amendments and supplements. To these ends experiments, amounting to about seventy every year, are distributed at centres chosen in consultation with the department of Soil Survey, designed and evaluated in collaboration with the section of Statistics, and repeated over a number of years to cover seasonal variations. Grateful acknowledgement is again made to the numerous farmers whose willing and efficient co-operation makes this approach possible.

The pot and laboratory investigations are all based on soils from field experiment areas so that the results can be assessed against appropriate aspects of field behaviour and crop performance. The pot experiments form an essential supplement to the field work and a connecting link with the laboratory studies. It is envisaged that their importance in these respects will increase as the overall research programme develops and understanding of field-pot relationships improves. Plans are therefore well advanced for new installations incorporating improved facilities and more refined control, to extend the scope as well as the scale of pot experiment studies.

Importance continues to be attached to the practical improvement of manurial practices and crop production through the medium of advisory soil testing in collaboration with the North of Scotland College of Agriculture. The practical implications of research findings are also covered in contributions to the agricultural press and lectures to various agricultural and horticultural organizations. In this connection, an assessment of the potential for greater fertilizer usage in Scotland[17], mentioned in last year's report, has been published. At the invitation of the organizing committee a paper on chemical soil tests as an aid to increased soil productivity[47] has been prepared for the Joint Meeting of Commissions IV and V of the International Society of Soil Science to be held in New Zealand during November.

The department continues to be represented on the Field Trials and Grassland Committees of the Scottish Agricultural Improvement Council, the Scottish Sub-committee of the Sugar Beet Research and Education Committee, and occasional Working Parties set up by the Agricultural Research

Council to assess manurial problems and related questions. Collaboration has also been maintained with the Agricultural Research Council Unit of Statistics in the preparation of reports on the Survey of Fertilizer Practice carried out by the Scottish Colleges of Agriculture, and with the Hill Farming Research Organization, the Animal Diseases Research Association, the Rowett Research Institute, and other research and technical bodies.

Dr J. W. S. Reith took part in the Fourth International Colloquium on Plant Analysis and Fertilizer Problems, held in conjunction with the Sixteenth International Horticultural Congress in Brussels in September 1962, and in a symposium on magnesium in relation to soils, crops, and animals, organized by the Agriculture Group of the Society of Chemical Industry in London in March.

The department took occupation of its new premises in September 1962. The major part of the removal was accomplished with very little disruption of normal activities, but the detailed reorganization of the various procedures for dealing with the numerous soil, crop, and fertilizer samples associated with the field and pot experimental work and advisory activities will take some time to complete. In the planning of the new laboratories, major importance was attached to the provision of adequate space and arrangements for the reception and preparation for analysis of soil and crop samples. Specially designed facilities have been provided for the drying and sieving of soils and a new high capacity oven with trays on a removable truck has been installed for drying crop samples. The much improved and more adequate accommodation and equipment will also facilitate the organization of the large-scale analytical requirements and make possible the extension of laboratory research projects. For the latter a Unicam S.P. 500 spectrophotometer has been purchased for more detailed and critical analytical estimations and should be particularly useful for the determination of certain nitrogen- and phorphorus-containing compounds in soil organic matter.

*Crop Responses to Fertilizers.* The series of annual factorial field experiments designed to measure the responses and two-factor interactions produced by applying N, P, and K has been continued. A paper[48] containing the main results, covering yield and chemical composition, from the series on swedes and turnips during the period 1948-58 has been accepted for publication. Some of these experiments also measured the effect of farmyard manure (FYM). About half the K in FYM seems to be available to the first crop after application, greatly reducing the response to and need for fertilizer K. The corresponding proportion for N and P, however, is small, and the amounts required from fertilizers can only be reduced by about 15 lb. of N and $P_2O_5$ per acre when FYM is applied. A striking feature of the experiments is the great variation between soils in the responses to N, P, and K. The two-factor interactions are small, but the response to K is usually increased by both N and P. The results indicate that at current prices the average most profitable rates in the absence of FYM are about 65 lb. N, 125 lb. $P_2O_5$, and 125 lb. $K_2O$, compared with about 50 lb. N, 110 lb. $P_2O_5$ and 55 lb. $K_2O$. in the presence of FYM.

Further work is in progress to obtain more refined measurements of the effects of FYM, and in other experiments preliminary comparisons are being made of NPK fertilizers in solid and liquid form.

*Methods and Times of Fertilizer Application.* The series of experiments on the time of application of N for barley has been completed and the results are being prepared for publication. Further comparisons of broadcast and band applications of different phosphate fertilizers, including triple superphosphate solution, are being carried out on swedes. Corresponding results from 1960 indicate that the gain from band placement of phosphate solution is similar to that obtained with granular superphosphate.

*Trace Elements.* Field experiments measuring the initial and residual effects of cobalt, copper, manganese, and zinc applications are being continued. The supplementary analytical work is carried out by the department of Spectrochemisty, and a joint paper[38] on the effects of additions of lime, fertilizers, and some trace elements on the contents in plants was presented at the Fourth International Colloquium on Plant Analysis and Fertilizer Problems, mentioned earlier. Liming generally lowers the cobalt, manganese, and zinc contents of herbage, but tends to increase the molybdenum content. Phosphate and potassium have no large effects but nitrogen reduces the manganese content. Dressings of cobalt, copper and molybdenum usually raise the plant content, the increase produced by molybdenum being very large, especially in clover. These increases, particularly for molybdenum, illustrate the potential dangers of indiscriminate application of trace elements and emphasize the point that they should normally be applied only where a definite need has been established.

*Calcium and Magnesium.* Field and laboratory work designed to study the influence of both liming and manuring on the magnesium contents of soils and crops has been extended. A paper summarizing the long-term effects of a range of liming materials[18], mentioned in last year's report, has now appeared, and an account of the magnesium contents of soils and crops, including effects of magnesium dressings [49], has been submitted for publication. These results were presented at a meeting of the Agriculture Group of the Society of Chemical Industry in London on 13th March. Fewer than 20 per cent of the soils examined from the northern half of Scotland had exchangeable magnesium contents of 3 mg. or less per 100 g., and these were mainly light sandy soils, deficient in lime. It would appear that the possibility of obtaining a yield response to magnesium is small and that the main justification for applying magnesium is to ensure adequate levels in crops and herbage to meet animal requirements. Field experiments are being continued to examine the effects of various magnesium supplements and the influence of nitrogen and potassium manuring on magnesium uptake. So far, the indications are that dressings of potassium required to produce satisfactory yields of herbage have little influence on its magnesium content.

*Nitrogen and Potassium.* Field and laboratory characterizations of the N and K status of different soil types have been continued. Other questions

being examined are the comparative effects of K applied as chloride, sulphate, nitrate, and bicarbonate on the yield and dry matter content of potatoes, and the fixation of atmospheric nitrogen by clover in the absence and presence of fertilizer N. The latter investigations underline the importance of clover in the nitrogen economy of grassland and emphasize the point that any treatment which reduces clover content of the sward automatically increases the need for fertilizer N if production is to be maintained.

*Inorganic Phosphorus.* Investigations embracing field, pot, and laboratory studies, and supplementary evaluations with the aid of radioactive phosphorus in collaboration with the section of Radioactivity of the department of Plant Physiology, have been continued and extended. An account of some of the main conclusions which have been reached[19] has appeared, covering implications of parent material and drainage conditions in relation to the distribution of soluble aluminium and iron and the pivotal roles of phosphate retention capacity and degree of saturation in relation to phosphate status and placement effects. Major importance continues to be attached to studies on the residual effects of phosphate in different soil types and the effectiveness of different forms of phosphate, including an examination of the possibility that organic forms, especially inositol hexaphosphate, may exert an indirect beneficial effect on P status by immobilizing active aluminium and iron. In the latter connection an account of a collaborative study with Dr S. M. Bromfield, Division of Plant Industry, C.S.I.R.O., Australia, on the biological reduction method for the estimation of active iron has been prepared for publication. A joint paper covering the application of radioactive phosphorus to evaluate soil P status and to investigate the significance of readily soluble P values by conventional extraction methods is being prepared for publication in collaboration with the section of Radioactivity.

*Organic Phosphorus.* The detailed examination and quantitative determination of soil organic phosphate and its individual components have been extended. A paper describing the partial fractionation of the phosphate esters in soil[20] has appeared and accounts of the determination of total soil organic phosphate[50] and the adsorption of phosphate esters by soil clays[26] have been accepted for publication.

Further progress has been made in the study of soil phospholipids and two papers describing their estimation[51] and the identification of some hydrolysis products[52] have been accepted for publication. Values reported in other areas have indicated that only a small proportion of soil organic phosphate is in lipid form, but they were obtained by measuring the phosphate soluble in alcohol and ether. It has been shown that these solvents do not quantitatively extract soil lipids and an improved procedure has been used in which the soil is extracted first with hydrochloric and hydrofluoric acids, followed by a number of organic solvents. The combined organic extracts are evaporated and the residue re-extracted with specific lipid solvents. Values obtained are much higher than with other methods, but

only account for 0·6 to 0·9 per cent of the soil organic phosphate. While further variation in extraction technique might increase the values slightly it is confirmed that the phospholipids make up only a very small proportion of the organic phosphate. Examination of the extracted material has confirmed the presence of the lipid components glycerophosphate, choline, and ethanolamine. Serine and inositol could not be detected. It seems likely that phosphatidylcholine is one of the predominant phospholipids in the soil.

An investigation has been completed on the effect of iron on the extraction of phytin from plant material and of the iron/phosphorus ratio on its subsequent estimation by the precipitation of its ferric salt. It has been found that the fulvic acid fraction of soil organic matter contains phytin in a bound form, and the nature of the binding is being investigated.

An account of a collaborative study with the department of Microbiology on the effect of trace element deficiency on the nucleic acid content of the soil actinomycete *Nocardia opaca*[10] has been published.

*Cation-exchange Properties of Plant Tissues.* Collaborative studies with the department of Plant Physiology have been extended, with particular reference to (a) the mineral composition of a wide range of natural vegetation and agricultural and horticultural crops, and (b) the relationship between the cation-exchange capacity (C.E.C.) and uronic acid content of lower plants (fungi, yeasts, algae) and of the different parts (roots, stems, leaves, seeds, and pollen) of *Angiosperms* and *Gymnosperms*. The latter studies indicate that within a plant the various tissues have much the same C.E.C., indicating that it is a fundamental characteristic of the species. Two papers on these investigations[14, 15] have appeared during the year.

*Advisory Work.* Over 15,000 soil samples, taken mainly from agricultural land by the staff of the North of Scotland College of Agriculture, were examined for advisory purposes. Collaboration continues in the analysis of samples from forest nurseries with the section of Forest Soils, and in the examination of plant and soil samples from areas with special problems of crop growth or animal health with the departments of Spectrochemistry and Plant Physiology. In a few cases a temporary shortage of moisture during late May or June was responsible for unsatisfactory growth in low rainfall districts.

The records for samples examined in 1960 indicate that in most districts the area of rotation land which is very deficient in lime is gradually decreasing, but that nearly two-thirds of the samples came from fields requiring 1-2 tons of calcium carbonate per acre.

## STATISTICS

Towards the end of the year the section moved into offices in the new building. In so far as a service is provided for other departments in the Institute, this move will facilitate opportunities for contact and collaboration and consequently increase the volume of planning of experimental projects and of subsequent analysis of data and reporting of results.

Mr R. H. E. Inkson attended the Summer Meeting of the Biometric Society at the Forest Research Station, Alice Holt Lodge, where considerable interest was shown in a machine for the direct recording of field observations on punched tape. Mr Inkson also attended a course on the Elliott autocode and on the use of the Elliott 803 electronic computer at the University of Aberdeen. Most of the computing work is still done on electric calculating machines, but some has been carried out on the electronic computers at Rothamsted Experimental Station and at the University of Aberdeen, to whom acknowledgement is made.

A high proportion of the work of the section arises from the field experiment programme of the department of Soil Fertility. Of the 60 experiments in this programme, more than half have been continued from previous years. For those commenced during the current year, experimental designs include randomized blocks, lattice squares, and various factorial designs, mostly with confounding of high-order interactions and some with split-plots. The analysis of the data from some experiments necessitates the fitting of concurrent response curves, particularly where several times or methods of application or forms of a fertilizer are being tested. A series of experiments in which this procedure is appropriate is concerned with the time of application of nitrogen for barley, and the combination of the results for the three areas, Aberdeenshire, Kincardineshire, and Midlothian, has been carried out.

Both multiple and partial correlation coefficients have been examined in a study of the influence of the soil content of magnesium, potassium, and calcium on the content of magnesium in herbage. Other correlation studies have been concerned with the investigation of the dependence of crop yield and uptake of phosphate on the phosphate content of the soil as measured by a number of extraction methods.

An account of the results from a series of confounded factorial experiments on the application to turnips and swedes of N, P, and K in the presence and absence of farmyard manure[48] has been accepted for publication. These experiments provide information on the responses to, and first-order interactions between, the three major nutrients, nitrogen, phosphate, and potassium, with the practical objective of indicating the most suitable levels of application. Second degree polynomials were fitted to the data to predict yield from the nutrients in the presence and absence of farmyard

manure. Hence, by maximizing profit, the optimum amounts of nutrients were obtained.

The methods of analysis of $3^2 \times 2^2$ and $3^3 \times 2$ confounded factorial experiments described in a paper[21] are of general application and have been used for other confounded factorial designs in order to obtain estimates of partially confounded treatment contrasts freed from block differences.

Closer collaboration with the section of Forest Soils in the design of experiments has brought about an increase in the volume of computional work and in the statistical evaluation of the results. The experimental designs used are randomized blocks, split-plot randomized blocks, latin squares, and factorial designs with and without confounding. The observations examined include measurements of height and girth and the results of foliage and soil analysis. The measurement of height or of height increment in the year prior to the application of treatments frequently proves to be a valuable concomitant observation and analysis of covariance increases the precision of the treatment comparisons.

A number of factorial experiments have been designed on behalf of the department of Plant Physiology. Observations on manganese, copper, iron, phosphorus, potassium, and calcium in mustard leaves were examined by means of analysis of covariance and correlation analysis in a study of the relationship between some of these variables and the ratios potassium/calcium, phosphorus/iron, and manganese/iron. An account of this work[42] has been accepted for publication. It also includes the results of analyses of covariance used to investigate the relationship between chlorosis and the ratios potassium/calcium, phosphorus/iron, and manganese/iron in leaves. An account of collaborative work with the departments of Plant Physiology and Soil Fertility, dealing with the relationship between the uronic acid content and the cation-exchange capacity of plant roots[14], has been published. Work on this subject with observations on various plant parts is continuing.

Collaborative work with the North of Scotland College of Agriculture has included the planning of a further group of three potato experiments of $3^2 \times 2$ confounded factorial design with some additional treatments and the analysis of data and the reporting of results for the corresponding 1961 series. Results were also examined from a time test of wear on a force-feed fertilizer distributor. In each of two series of experiments on winter wheat combined analyses of results were carried out for a number of observations. One series, of randomized block design, tested differences between times of application of nitrogen. In the other series, a split-plot design was used to test the main effects and the interactions between the factors, time of application of nitrogen, seed rate, and sowing date.

Further series of experiments, based on the $3^3$ factorial design have been planned for potato and swede crops in collaboration with the Crop Husbandry Department of the West of Scotland Agricultural College. Measurements of yield and other observations have been examined and reports submitted for one early and two main crop potato experiments and for three swede experiments carried out during 1961.

For the greater part of the year the section was accommodated in the Department of Statistics of the University of Aberdeen, where a course of statistical technique lectures on biometric practice in forestry was given to Honours degree students. Acknowledgement is made to the University of Aberdeen, and in particular to Dr D. J. Finney, F.R.S., for courtesies shown.

## LIBRARY

The library is primarily for the use of Institute staff, but books and journals are lent to other libraries and to individuals either on direct application or through the inter-library lending schemes. The stock of the library covers most branches of soil science and related fields, and a list of periodical holdings is available on request. During the year 140 items were lent to external borrowers and 521 loan requests were made to other libraries.

The widespread interest in the work of the Institute is reflected in the number of requests received from all over the world for reprints of staff papers: this year 918 requests were dealt with. Annual reports and reprints are supplied free of charge to anyone interested in the research activities of the Institute. Lists of available reprints are issued, and arrangements can be made for anyone wishing to receive these to be placed on the mailing list. Exchange material is appreciated.

The library has now been in the new building for over a year, and the advantages of the improved accommodation are daily apparent in the routine running of the library.

# PUBLICATIONS

(A) *Published—*

1. The influence of soil-forming factors on clay genesis. By B. D. Mitchell. (pp. 139-147 of *Genèse et synthèse des argiles. Colloq. int. Cent. nat. Rech. Sci.*, No. 105, 1962.)

   An assessment of clay mineral genesis in relation to soil formation in south-west Scotland shows that parent material, relief, climate, and living matter have important individual and combined effects. Thus, a high kandite content can be related to the acidity of the parent material and to the rate of leaching. The transition from non-expandable to expandable clays is influenced by soil drainage and the availability of cations. The organic matter content, the permeability of the parent material, and microbial activity are closely associated with the occurrence of amorphous clays.

2. The ageing of sesquioxide gels. II. Alumina gels. By R. C. Mackenzie, R. Meldau (Gütersloh, Germany), and J. A. Gard (University of Aberdeen). (*Miner. Mag.*, **33**, 145-157, 1962.)

   Aluminium oxides occur widely in soils and are of considerable pedological significance. The ageing of alumina gels, prepared from aluminium chloride and ammonia into crystalline hydroxides has been investigated using thermal, X-ray, infrared, and electron-microscope techniques. At room temperature ageing is more rapid at high pH values. The structure of the original gel particles appears to resemble boehmite and ageing causes the formation of bayerite with small amounts of gibbsite. The morphology of the various mineral types is considered and a mechanism of ageing suggested.

3. Differential thermal analysis: a review. By R. C. Mackenzie and B. D. Mitchell. (*Analyst*, **87**, 420-434, 1962.)

   A review article discussing differential thermal analysis from the viewpoint of its analytical applications.

4. Some aspects of peat as a substrate for tree growth. By W. O. Binns. (*Irish For.*, **19**, 32-55, 1962.)

   Investigations at 12 deep peat sites in Scotland and North England have suggested that the needs of conifers for additional phosphate and potash may be estimated from the total phosphate and potash contents of the upper layers of the peat; concentration of these two nutrients in the surface layers, attributed to recycling by the natural vegetation, indicates that although deep rooting may improve stability it will probably not benefit trees much nutritionally. Mineralization of nitrogen, more rapid in deep than in shallow plough ridges, appears to be responsible for faster growth of young pine and larch on deep ridges. The deficiency of potash found at some of the sites is confirmed by comparing the maximum amounts of nutrients immobilized by conifers with the nutrients present in peat.

5. An improved method for the placement of radioactive isotopes in the study of root systems of plants growing in deep peat. By R. Boggie and A. H. Knight. (*J. Ecol.*, **50**, 461-463, 1962.)

   The method described enables two operators to place a radioactive tracer at any given depth in peat more accurately and quickly than before and without risk of contamination of the surface vegetation.

6. The general principles of classification with reference to soils. By J. W. Muir. (*J. Soil Sci.*, **13**, 22-30, 1962.)

   By tracing the development of classification in the fields of plants and chemical

elements, it has been possible to demonstrate a pattern of development which may hold for soil classification. Development is bound up with the use of artificial and natural systems of classification. Since there is still controversy about the character of artificial and natural systems, definitions for both are proposed and examples of each given. A brief outline of the development of soil classification shows it to be at an early stage of development, although systems recently published give promise of significant advances in the near future.

7. The trace-element content of fertilizers. By D. J. Swaine. (*Technical Communication No. 52, Commonwealth Bureau of Soils.* pp. xiv, 306. Price 40/-. 1962.)

A survey of the literature, covering the contents of over 60 elements in N, P, and K fertilizers, liming materials, organic manures, and miscellaneous additives including industrial wastes, slags, and soil amendments.

8. The application of direct-reading spectrochemical methods to soil analysis. By R. O. Scott. (*Trans. VII Int. Congr. Soil Sci.* (*Madison*), **2**, 10-15, 1960.)

The applications of two direct-reading spectrometers to the determination of Mg, Al, Cu, Mn, and Zn in soil extracts are described. A tentative method for the determination of Zn, B, Mn, and Cu in ashed plant materials is also described.

9. Infrared study of adsorption of water and aromatic compounds on alkali halides. By V. C. Farmer and J. D. Russell. (*Spectrochim. Acta*, **18**, 461-466, 1962.)

The pressed disk technique is widely used for infrared studies of humic acids and related materials, but the interpretation of their hydroxyl absorption bands is rendered uncertain by the observation that alkali-halide pressed disks containing simple aromatic compounds with no hydroxyl groups may yet show strong hydroxyl absorption bands. It is shown that this hydroxyl absorption arises from adsorbed water which, although always present on finely ground alkali halides, is greatly increased in amount when certain aromatic compounds are present during the grinding process. The increased adsorbed water is correlated with adsorption of the aromatic compounds on the alkali halides. It can be reduced to low levels by heating the disks to between 100° and 200°.

10. The metabolism of iron-, zinc-, and manganese-deficient *Nocardia opaca*. By D. M. Webley, R. B. Duff and G. Anderson. (*J. gen. Microbiol.*, **29**, 179-187, 1962.)

One important aspect of trace element work is the elucidation of the role of these elements in the metabolism of plants and animals. In this paper certain aspects of the physiology of iron-, zinc-, and manganese-deficient cells of a soil micro-organism (*Nocardia opaca*) have been investigated. It has been found that (a) deficiency of zinc upsets the breakdown of the reserve carbohydrate in the cell, (b) deficiency of manganese prevents normal deoxyribonucleic acid synthesis, and (c) iron deficiency prevents catalase formation and affects the breakdown of certain substrates by the organism. These findings may be a guide to the role of these trace elements in the metabolism of other biological material.

11. A technique for investigating localized microbial development in soils. By D. M. Webley and R. B. Duff. (*Nature*, **194**, 364-365, 1962.)

Details are given for studying the localized development of micro-organisms in soils. Soluble substances are mixed in powdered form with the inert base (kaolinite) and compressed into pellets of uniform size which are buried in soil. As the soluble material diffuses out of the pellets an enrichment of organisms takes place on them. The pellets are removed at suitable intervals and dilution plate counts performed. These counts are compared with those from similar pellets, containing only the inert base, buried in the same soil under identical conditions. Using this technique an enrichment of bacteria has been found on glucose/kaolinite pellets buried in garden

soil. 2-ketogluconic was also detected and estimated in this soil. The technique, therefore, may be of value in studying not only the localized development of micro-organisms in microhabitats but also in some cases their physiological activity in these sites.

12. The occurrence of 2-*O*-methylrhamnose and 4-*O*-methylgalactose in soil and peat. By R. B. Duff. (*J. Sci. Fd Agric.*, **12**, 826-831, 1961.)

The water soluble polysaccharides in soil are thought to have some influence on the crumb structure of fertile soils. This paper continues investigations on the composition and structure of the soil polysaccharides. Two methylated sugar units are identified in it. Following the suggestion that these methylated units act as "stoppers" to polysaccharide biosynthesis, it is thought possible that they may explain the slow rate of decomposition of the polysaccharides in soil as compared to rapidly decomposed plant residues. The soil polysaccharide is thought to be of microbial origin and the evidence for this is discussed.

13. The effects of natural and synthetic chelating substances on the mineral status of plants. By P. C. DeKock. (*Trans. VII. Int. Congr. Soil Sci.* (*Madison*), **3**, 573-579, 1960.)

The fertilizing effect of a lignite has been related to its chelating effect on iron which is then rendered available for absorption by the plant. A study has been made of synthetic chelating substances in relation to their growth promoting effect. This has been ascribed to the stability of the chelate molecule, the greater the stability the more effective the growth promoting effect of the chelating agent. It would appear that to a certain extent the whole chelate is taken into outer cells of the root, the iron or other chelated metal being subsequently liberated by metabolic processes. The chelating substances affect the mineral composition of the plant in so far as they cause an improvement in the iron status of the plant with associated changes in the phosphorus, potassium, and calcium contents of the plant.

14. Cation-exchange capacities of tissues of higher and lower plants and their related uronic acid contents. By A. H. Knight, W. M. Crooke, and R. H. E. Inkson. (*Nature*, **192**, 142-143, 1961.)

As part of a larger investigation on the mineral composition of plants, the cation-exchange capacity of roots was examined. By sampling natural vegetation embracing 80 Angiosperm spp. a positive relationship has been found between the cation-exchange capacity of the roots and their uronic acid content which is largely independent of a wide range of soil types, pH, and drainage conditions. The relationship holds also for Gymnosperms and lower plants (ferns, mosses, algae, and fungi).

15. An evaluation of published data on the mineral composition of plants in the light of the cation-exchange capacities of their roots. By W. M. Crooke and A. H. Knight. (*Soil Sci.*, **93**, 365-373, 1962.)

Although the contribution of the soil to the mineral composition of the plant has been studied, the possible influence of the plant itself has tended to be neglected. Resulting from work with the natural vegetation, the property which plant roots have of adsorbing and exchanging cations with the soil is now thought to play some part in determining the mineral content of the plant. This property, the cation-exchange capacity (C.E.C.) of the roots has been used to evaluate published data on crop plants, grasses, and legumes from U.S.A. and Germany. The C.E.C. has been shown to be related to (a) the total cation content (Ca+Mg+K+Na) of the plant, (b) the ash, (c) the excess base, and (d) the total trace elements (Fe+Mn+Cu+Zn). In addition the C.E.C., and more especially the ash content, is related directly to the protein, fats, and waxes in the plant, and inversely to the crude fibre content. The soluble carbohydrates appear to be almost independent of ash content.

16. Evaluation of the plate technique in use for studying phosphate-dissolving micro-organisms. By D. M. Webley. (*Trans. VII Int. Congr. Soil Sci.* (*Madison*), **2,** 657-663, 1960.)

An account is given of the various techniques in use for obtaining insoluble phosphates in agar medium. It is shown that the method of direct incorporation of finely divided suspensions, prepared in a ball mill, has many advantages over the chemical precipitation method. Thus it gives better control over the nature of the final product in the plates and increases the range of insoluble substances which can be studied to include naturally occurring materials such as rock phosphates.

17. The potential for greater fertilizer usage. By J. W. S. Reith. (*J. Inst. Corn Merch.* **9,** 149-151, 1961.)

The article assesses the amounts of nitrogen, phosphate and potash supplied by fertilizers which are required in Scotland to produce the most profitable yields of crops and rotation grassland, and to improve gradually the permanent grass. It appears that, with some small adjustments, the tillage crops are getting approximately optimum rates at current prices. The yields of grassland herbage could be greatly increased by applying fertilizers, but other factors limit the amounts considered adequate under present conditions. More fertilizer, especially phosphate, could be usefully applied to the permanent grassland and the position of the rough grazings is briefly considered.

18. Long-term effects of various liming materials. By J. W. S. Reith. (*Emp. J. exp. Agric.*, **30,** 27-41, 1962.)

The effectiveness of a range of liming materials has been measured in three field experiments carried out over a period of 12 to 14 years. The data for the first five years were reported previously and the subsequent results for the effects on the yield and composition of the crops and on soil properties are presented. There are no large differences in the residual values of the various materials. The average annual losses of calcium and magnesium from the soil have been calculated.

19. Some aspects of phosphate retention and availability in soils. By E. G. Williams. (*Trans. VII Int. Congr. Soil Sci.* (*Madison*), **3,** 604-611, 1960.)

The phosphorus relationships in acid surface soils derived from contrasting glacial tills in north-east Scotland show marked effects of parent material which hinge ultimately on varying contents of acid-oxalate soluble Al and Fe. The phosphate retention capacity ranges from 0·5 to 3·0 per cent. $P_2O_5$ and depends mainly on soluble Al, but it is also significantly correlated with acid-oxalate soluble Fe and with loss of ignition and carbon. The latter relationships derive mainly from strong Al-C correlations, and major proportions of the active Al, and possibly Fe also, probably occur in intimate association with organic matter. Phosphorus content is significantly correlated with retention capacity. The degree of saturation gives a significant criterion of phosphate status, and organic phosphates like inositol hexaphosphate probably fulfil a useful function by partially satisfying the retention capacity. High retention capacity is associated with lower crop responses but relatively higher effectiveness of placed compared with broadcast phosphate.

20. A partial fractionation of alkali-soluble soil organic phosphate. By G. Anderson. (*J. Soil Sci.*, **12,** 276-285, 1961.)

A study has been made of the precipitation of organic phosphates from alkaline extracts of soils derived from basic igneous, slate, granitic and Old Red Sandstone glacial drift. Acidification to low pH values brought down from 8 to 19 per cent. of the extracted phosphate, the amount being unaffected by the sesquioxide content of the

extracts. At pH values about 3, on the other hand, the precipitation of organic phosphate was critically affected by iron and aluminium, and in the presence of excess aluminium up to 83 per cent. of the extracted organic phosphate was brought down. Inositol hexaphosphate and deoxyribonucleic acid (DNA) were precipitated virtually quantitatively at pH 2·9 in the presence of added aluminium sulphate, even if the extract was incubated before precipitation. Precipitation of ribonucleic acid (RNA) was not complete and could be prevented entirely by prior incubation of the extract. At pH 0·2 DNA was precipitated, but not inositol hexaphosphate. Less than half of a freshly purified sample of RNA was brought down, and no precipitation occurred if the RNA was allowed to stand overnight in alkaline solution before acidification. The soil phosphate esters have been divided into three main classes—an acid-insoluble fraction precipitated at pH 0·2, and two acid-soluble fractions, one of which is precipitated at pH 2·9 in the presence of excess aluminium while the other remains in solution.

21. The analysis of a $3^2 \times 2^2$ factorial experiment with confounding. By R. H. E. Inkson. (*Appl. Statist.*, **10**, 98-107, 1961.)

The analysis of a $3^2 \times 2^2$ factorial experiment in blocks of 6 plots is described and details given of a general method for computing estimates of confounded treatment contrasts together with their standard errors. The relative information on these partially confounded contrasts freed from block effects is presented and the validity of the analysis is discussed.

(B) *Submitted—*

22. The quantitative determination of minerals in clays. By R. C. Mackenzie. (To appear in *Acta Univ. Carol., Geol.*, Suppl. **1**, 11-21, 1961.)

23. The quantitative determination of halloysite, goethite and gibbsite. By R. C Mackenzie and R. H. S. Robertson (Pitlochry). (To appear in *Acta Univ. Carol., Geol.*, Suppl. **1**, 139-149, 1961.)

24. *De natura lutorum.* By R. C. Mackenzie. (To appear in *Clays and Clay Minerals: Proc. XI Nat. Conf. on Clays and Clay Minerals, Ottawa, 1962.*)

25. Infrared, X-ray and thermal analysis studies of some aluminium and ferric phosphates. By E. Z. Arlidge, V. C. Farmer, B. D. Mitchell, and W. A. Mitchell. (To appear in *J. appl. Chem.*, **13**, 17-27, 1963.)

26. The adsorption of inositol phosphates and glycerophosphates by soil clays, clay minerals, and hydrated sesquioxides in acid media. By G. Anderson and E. Z. Arlidge. (To appear in *J. Soil Sci.*, **13**, 216-224, 1962.)

27. The dehydroxylation and rehydroxylation of triphormic dioctahedral clay minerals. By L. Heller (Geological Survey, Israel), V. C. Farmer, R. C. Mackenzie, and B. D. Mitchell, and H. F. W. Taylor (University of Aberdeen). (To appear in *Clay Min. Bull.*, **5**, 56-72, 1962.)

28. Amorphous clay minerals in some Scottish soil profiles. By B. D. Mitchell and V. C. Farmer. (To appear in *Clay Min. Bull.*, **5**, 128-144, 1962.)

29. Weathering of some Scottish basic igneous rocks with reference to soil formation. By Wilma W. Smith. (To appear in *J. Soil Sci.*, **13**, 202-215, 1962.)

30. A punched-card system for soil profiles. By J. W. Muir and H. G. M. Hardie. (To appear in *J. Soil Sci.*, **13**, 249-253, 1962.)

31. Peat: its origin, properties and use in horticulture. By R. A. Robertson. (To appear in *Sci. Hort.*)

32. The soils of the country round Aberdeen, Inverurie and Fraserburgh. By R. Glentworth and J. W. Muir. (To appear as *Memoir of the Soil Survey of Great Britain: Scotland.*)

33. The principal genetic soil groups of Scotland. By R. Glentworth. (To appear in *Proc. Joint Meeting Comm. IV and V Int. Soc. Soil Sci., New Zealand, 1962.*)

34. The soils of north-east Scotland. By R. Glentworth. (To appear in handbook for *Brit. Assoc. Adv. Sci. Meeting, Aberdeen, 1963.*)

35. The origin of the indurated $B_3$ horizon of podzolic soils in north-east Scotland. By J. C. C. Romans. (To appear in *J. Soil Sci.*, **13**, 141-147, 1962.)

36. Copper-deficient soils in south-east Scotland. By D. Purves (Edinburgh and East of Scotland College of Agriculture) and J. M. Ragg. (To appear in *J. Soil Sci.*, **13**, 241-246, 1962.)

37. A method of determining the relative ages of readvance moraines. By J. C. C. Romans. (To appear in *Scot. geogr. Mag.*)

38. The effect of soil treatment on trace element uptake by plants. By J. W. S. Reith and R. L. Mitchell. (To appear in *Proc. IV Int. Colloq. Plant Anal. Fert. Problems.*)

39. Trace analysis by spectrochemical methods. By R. L. Mitchell. (To appear in *Proc. Feigl Anniv. Symp.*)

40. The solubilization of minerals and related materials by 2-ketogluconic acid-producing bacteria. By R. B. Duff, D. M. Webley, and R. O. Scott. (To appear in *Soil Sci.*)

41. Changes in the concentrations of malic and citric acids, calcium, and potassium in leaves during the growth of normal and iron-deficient mustard plants (*Sinapis alba*). By M. J. Palmer, P. C. DeKock, and J. S. D. Bacon. (To appear in *Biochem. J.*, **86**, 484-494, 1963.)

42. Manganese content of mustard leaves in relation to iron and major nutrient supply. By P. C. DeKock and R. H. E. Inkson. (To appear in *Plant Soil*, **17**, 183-190, 1962.)

43. The effect of nutrient concentration upon the growth and mineral composition of mustard plants. By P. C. DeKock and A. Hall. (To appear in *Agrochimica*, **7**, 89-95, 1962.)

44. Kinetic studies of anion absorption by potato slices at 0°C. By I. R. MacDonald and G. G. Laties (University of California, Los Angeles). (To appear in *Plant Physiol.*)

45. Oxygen electrode measurements of potato slice respiration at 0°C. By I. R. MacDonald and G. G. Laties (University of California, Los Angeles). (To appear in *J. exp. Bot.*, **13**, 435-442, 1962.)

46. The microbiology of rocks and weathered stones. By D. M. Webley, Moira E. K. Henderson and Irene F. Taylor. (To appear in *J. Soil Sci.*)

47. Chemical soil tests as an aid to increased productivity. By E. G. Williams. (To appear in *Proc. Joint Meeting Comm. IV and V Int. Soc. Soil Sci., New Zealand, 1962.*)

48. Effects of fertilizers and farmyard manure on swedes and turnips. By J. W. S. Reith and R. H. E. Inkson. (To appear in *J. agric. Sci.*)

49. The magnesium content of soils and crops. By J. W. S. Reith. (To appear in *J. Sci. Fd. Agric.*)

50. A comparative study of methods of estimating soil organic phosphate. By R. J. Hance and G. Anderson. (To appear in *J. Soil Sci.*, **13**, 225-230, 1962.)

51. The extraction and estimation of soil phospholipids. By R. J. Hance and G. Anderson. (To appear in *Soil Sci.*)

52. The identification of hydrolysis products of soil phospholipids. By R. J. Hance and G. Anderson. (To appear in *Soil Sci.*)

## THESIS

The following thesis has been accepted by the University of Aberdeen for the degree of Doctor of Philosophy.

*A study of the trace element uptake of deciduous trees.* By M. M. Guha.